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LOW-SPEED INVESTIGATION OF THE EFFECTS OF LARGE
WING-SIDESLIP ANGLES ON THE AERODYNAMIC CHARACTERISTICS
OF TWO ARROW-WING-FUSELAGE ARRANGEMENTS

By Thomas G. Gainer

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SUMMARY

A wind-tunnel investigation has been made of two methods proposed to reduce the high sinking speeds and improve the landing characteristics of low-aspect-ratio hypersonic airplanes by placing the wing at large angles of sideslip to increase its effective aspect ratio. The models investigated had conical fuselages and arrow wings, with a leading-edge sweep-back of 77.4° , an aspect ratio of 1.23, and a 4-percent-thick straight-wedge section. For one model, the wing was pivoted on the fuselage to angles of wing sideslip from 0° to 90° . For the other model, the wing was fixed to the fuselage, and the wing and fuselage were yawed together to sideslip angles from 0° to 90° . The investigation was made in the Langley 300-MPH 7- by 10-foot tunnel for an angle-of-attack range from -8° to above 28° . Longitudinal stability and control through the use of horizontal tails with elevators was studied on the pivoted-wing configuration. The roll control for both configurations was studied with deflection of the apex portion of the wing about an axis along the wing center line. The use of flaps with the wing at large sideslip angles was also investigated.

The results of the investigation showed that sideslipping the fixed-wing model to large angles presented longitudinal and lateral stability and control problems and did not provide sufficient aerodynamic improvement to warrant a consideration of this method of improving landing performance for the configuration tested. The pivoted-wing arrangement, on the other hand, appears to offer low-speed aerodynamic improvement for low-aspect-ratio configurations if longitudinal stability and control capabilities are provided and directional and roll control can be obtained. With the wing pivoted to 90° sideslip, the pivoted-wing model with horizontal tails and elevators had static longitudinal stability except at the lower lift coefficients, and longitudinal trim was provided up to maximum lift coefficient. Deflecting the apex portion of the wing provided roll control for only a limited angle-of-attack range with the wing pivoted 90° . Calculations of the flare of a hypothetical pivoted-wing airplane indicate considerably lower values of landing speed and steady-state rate of sink

than usually predicted for arrow-wing configurations. The minimum sink rate obtained, however, was still higher than what is generally considered desirable.

INTRODUCTION

The landing problem promises to be severe for airplanes designed to obtain high lift-drag ratios at hypersonic speeds (ref. 1). The main source of difficulty is the high power-off rate of sink of these configurations resulting from the low aspect ratio of the wings. A possible solution to this problem, however, might be in the fact that these wings would have relatively high aspect ratios if turned perpendicular to the airstream, and to do this, two possible methods have been proposed. First, the entire airplane might be yawed to fly at large angles of sideslip. Second, with the proper mechanism the wing itself might be pivoted on the fuselage of the vehicle, with the resulting configuration resembling a relatively high-aspect-ratio airplane. This second scheme was investigated in reference 2 and might also find application in the take-off maneuver. It offers possibilities of providing stability and control in the landing maneuver because of a mounting platform for a horizontal tail provided by the fuselage. This report presents some low-speed aerodynamic data to aid in evaluating the feasibility of these proposals.

The investigation was made on an arrow wing with a conical fuselage similar to those of references 1 and 3. For tests to explore the pivoted-wing principle, the arrow wing was pivoted on top of an elongated fuselage equipped with horizontal tails. These models were investigated to extend the study of the yawed-wing scheme of reference 2 to configurations more representative of hypersonic configurations. The models were tested in the Langley 300-MPH 7- by 10-foot tunnel with either the complete model at an angle of sideslip or the wing pivoted on the fuselage to various angles of wing sideslip from 0° to 90° . A study was made of deflecting the forward portion of the wing about an axis along its center line as a roll control for both of these configurations during and after transition from high-speed to low-speed configuration. Pitch control was studied for the pivoted-wing configuration with horizontal-tail elevators. The models were also tested with single-slotted and plain-flap arrangements to give an indication of the possibilities of using a high-lift system on the yawed wing. Since "drooped" or deflected wing tips have been suggested for arrow-wing configurations, a deflected tip was used as a flap for some tests with the wing at a high aspect ratio.

SYMBOLS AND COEFFICIENTS

The force and moment coefficients of this paper are presented with reference to the wind-axes system as shown in figure 1. Moments for the models tested are referred to a point at 69.8 percent of the arrow-wing root chord. Pitching-moment and rolling-moment coefficients are based on the mean aerodynamic chord $\bar{c}$ and the span b , respectively, of the wing in the conventional position at zero sideslip.

S	wing area, 3.525 sq ft
$\bar{c}$	wing mean aerodynamic chord ($\beta_w = 0^\circ$), 2.098 ft
b	wing span ($\beta_w = 0^\circ$), 2.083 ft
q	dynamic pressure, $\frac{\rho V^2}{2}$, lb/sq ft
V	airspeed, ft/sec or knots
ρ	air density, slugs/cu ft
α	angle of attack, deg
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
C_D	drag coefficient, $\frac{\text{Drag}}{qS}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$
C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$
C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$
C_C	crosswind coefficient, $\frac{\text{Crosswind}}{qS}$
C_{L_α}	lift-curve slope, $\frac{\partial C_L}{\partial \alpha}$

$\delta_{t,l}$	deflection of left wing tip (positive with tip deflected downward), deg
γ	flight-path angle, deg
θ	airplane attitude referred to horizontal, deg
δ_a	roll-control (aileron) deflection (direction of positive deflection indicated in fig. 2(c)), deg
β_w	wing sideslip angle (refers to sideslip angle of both wing and fuselage for the fixed-wing model), deg
b'	wing span at a given angle of wing sideslip for $\beta_w > 0^\circ$ (can be derived as equal to $2.500 \sin \beta_w + 2.601 \sin (23.6^\circ + \beta_w)$), ft
A_m	modified wing aspect ratio, $\frac{(b')^2}{S}$
δ_e	elevator deflection (positive with trailing edge down), deg
V_s	sinking speed, ft/sec
L/D	lift-drag ratio, C_L/C_D
Subscript:	
max	maximum

MODELS AND APPARATUS

The geometric characteristics of the fixed-wing model and of the pivoted-wing model tested are given in figure 2. A photograph of the fixed-wing model is shown in figure 3. The models were tested in the Langley 300-MPH 7- by 10-foot tunnel on a single-strut support, with the six-component forces and moments being measured by a mechanical balance. The balance center was located at 69.8 percent of the wing root chord for both models, and moments in this paper are referred to this point.

The wings and fuselages were constructed of mahogany laminated to aluminum spars. The horizontal tails of the pivoted-wing model were 1/4-inch-thick aluminum plates with a rounded leading edge and a beveled trailing edge. These tails were designed so that they could be retracted into the cutout on the upper surface of the rear of the fuselage for the

high-speed flight configuration (fig. 2(b)). The elevators used were 25-percent extensions of the tail chord and consisted of 1/16-inch-thick metal plate attached to the lower tail surface and bent to give the desired elevator incidence. The apex portion of the arrow wing, forward of the 34.9-percent wing-root-chord station, could be deflected about an axis along the wing center line as an aileron or roll control with the wing yawed, as was done with the delta wing of reference 2. For the fixed-wing model, a portion of the fuselage was deflected with the nose portion of the wing. The tip of the arrow wing, the portion of the wing outboard of the 54.5-percent-semispan station, was deflected downward for some tests at an angle $\delta_{t,l}$ of 45° . The pivoted-wing model was tested with a 30° single-slotted flap, and the fixed-wing model was tested with both a 15° plain flap and a 30° single-slotted flap. The plain flap had a thin, flat-plate section; whereas the single-slotted flaps had highly cambered airfoil sections. Details of these control and flap arrangements are given in figure 2(c). The spans of the 30° single-slotted flaps were 14 inches for the pivoted-wing model and 18 inches for the fixed-wing model.

TESTS AND CORRECTIONS

Tests were made at a dynamic pressure of about 28 pounds per square foot, corresponding to a free-stream velocity of about 157 feet per second and a Reynolds number of about 9.07×10^5 per foot. An angle-of-attack range from about -8° to above 28° was investigated. The pivoted-wing model was tested with wing pivot angles of 0° to 90° with the fuselage remaining parallel to the airstream. The fixed-wing model was tested with the complete model yawed at angles of 0° , 45° , and 90° to the airstream. Both the wing-pivot point for the pivoted-wing model and the point about which the fixed-wing model was yawed were at 69.8 percent of the wing-root chord.

Jet-boundary corrections as determined by the methods of reference 4 were applied to the data as indicated by the following equations:

$$\alpha = \alpha_{\text{tunnel}} + 0.363C_L$$

$$C_D = (C_D)_{\text{measured}} + 0.0063C_L^2$$

The blockage correction as applied to the dynamic pressure was obtained by the method outlined in reference 5. The drag data were not corrected to the condition of free-stream pressure acting on the base of the model.

PRESENTATION OF RESULTS

The results of the investigation of the fixed- and pivoted-wing models are presented in the following figures:

	Figure
Longitudinal characteristics of the fixed-wing model:	
Effect of sideslip angle	4
Effects of modifications to the configuration	5
Lateral characteristics of the fixed-wing model:	
Effects of sideslip angle	6
Effects of roll-control deflection with -	
$\beta_w = 45^\circ$	7(a)
$\beta_w = 90^\circ$	7(b)
Effects of roll-control deflection with 15° plain flap on -	
$\beta_w = 45^\circ$	8(a)
$\beta_w = 90^\circ$	8(b)
Longitudinal characteristics of the pivoted-wing model:	
Effects of wing sideslip angle	9
Maximum L/D and the lift coefficient for maximum L/D	
as a function of wing sideslip angle	10
Variations of modified wing aspect ratio and	
lift-curve slope with wing sideslip angle	11
Contributions of wing, fuselage, and horizontal tails	
to the lift, drag, and pitching moment with $\beta_w = 90^\circ$	12
Effects with $\beta_w = 90^\circ$ of -	
Elevator deflection	13(a)
Roll-control deflection	13(b)
Effects with $\beta_w = 90^\circ$ and with 30° singled-slotted flap of -	
Elevator deflection	14(a)
Roll-control deflection	14(b)
Lateral characteristics of the pivoted-wing model:	
Effects of wing sideslip angle	15
Effects of roll-control deflection with -	
$\beta_w = 45^\circ$	16(a)
$\beta_w = 67.5^\circ$	16(b)
$\beta_w = 90^\circ$	16(c)
$\beta_w = 90^\circ$ with 30° single-slotted flap ($\delta_{t,l} = 45^\circ$)	16(d)
Variation of rolling-moment coefficient	
with roll-control deflection	17

Figure

Landing-performance characteristics of the pivoted-wing model ($\beta_w = 90^\circ$):	
Trimmed values of lift coefficient and L/D	18
Variation of power-off glide angle with flight speed for unaccelerated flight	19
Variation of angle of attack, glide angle, and attitude angle with sinking speed	20

DISCUSSION

Fixed-Wing Model

Longitudinal characteristics.— Sideslipping the fixed-wing model to large angles of sideslip did not provide sufficient aerodynamic improvement to warrant a consideration of this method of improving landing performance for a configuration of this type. Although yawing produced some increases in lift at a given angle of attack in the lower angle-of-attack range, L/D was reduced by the large drag contributed by the fuselage at the higher sideslip angles (fig. 4). The data of figure 5 show that mounting the fuselage above the wing gave poor results at $\beta_w = 90^\circ$, but with the fuselage below the wing, flaps could be used to provide some increases in both C_L and $(L/D)_{\max}$. It should be noted, however, that with the fuselage removed (fig. 5) the arrow wing at a sideslip angle of 90° developed much higher lift (especially with flaps) and L/D than at a sideslip angle of 0° (fig. 4), which gives an indication that yawing might result in substantial benefits if the wing-fuselage arrangement were properly designed to minimize fuselage-interference effects. This would involve reducing the fuselage thickness and blending it into the wing surface to reduce drag, which might also increase lift by increasing the camber of the lifting surface at large sideslip angles.

The pitching-moment data of figures 4 and 5 indicate some of the stability and control problems which would be involved in yawing a fixed-wing configuration to large sideslip angles. The fixed-wing model was longitudinally unstable with pitching moments referred to a point at 69.8 percent of the wing root chord. Yawing the model about this reference point had little effect on this instability, except in the lower lift-coefficient range where the model became more unstable as the angle of sideslip was increased. Provided a configuration developing relatively high lift and L/D at large sideslip angles could be designed, it appears that some sort of additional aerodynamic surfaces would be required if longitudinal stability and control at such attitudes were to be at all possible.

Lateral characteristics.- The nonlinear variations of rolling-moment coefficient with angle of attack and the out-of-trim yawing-moment coefficients obtained by sideslipping the fixed-wing model are shown in figure 6. The effects of the roll control on the lateral characteristics are shown in figure 7 with flap off and in figure 8 with the 15° plain flap added. At $\beta_w = 45^\circ$ the control was adequate for roll trim at angles of attack above 15° with flap off and below 20° with flap on. At $\beta_w = 90^\circ$ the negative values of C_l existing at the higher angles of attack could not be trimmed, even with the positive shift in C_l produced by the flap.

Pivoted-Wing Model

Longitudinal characteristics.- The pivoted-wing arrangement appears to offer low-speed aerodynamic improvement for low-aspect-ratio configurations if longitudinal stability and control capabilities are provided and directional and roll control can be obtained. The data of figure 9 and the cross plots of figure 10 show that substantial increases in lift coefficient and L/D were obtained by pivoting the wing to large angles of sideslip. These could be attributed to expected increases in lift-curve slope and reductions in drag because of the higher effective aspect ratio of the wing, and, also, to increments in lift produced by increases in the thickness-to-chord ratios of the streamwise-wing sections. There was considerable reduction in the angle of attack required for a given lift as a result of pivoting the wing (fig. 9). The increases in lift-curve slope produced, as measured from figure 9 over the portions of the lift curves through 0° angle of attack, are illustrated in figure 11 which also shows the modified aspect ratios of the arrow wing for the various wing sideslip angles. At the higher angles of attack the fuselage contributed a sizable portion of the lift developed at $\beta_w = 90^\circ$ (fig. 12); whereas adding the horizontal tails increased the lift only slightly while reducing $(L/D)_{\max}$.

The pitching-moment data of figure 9 show that the wing-fuselage combination was longitudinally unstable, with a reduction in static longitudinal stability occurring as the wing-sideslip angle was increased at the lower lift coefficients. At the lower wing sideslip angles there was a reduction in longitudinal stability with increasing lift probably due to a loss of lift near the wing tips as the angle of attack was increased; however, this effect was absent with the wing pivoted to higher angles. Adding the horizontal tails at $\beta_w = 90^\circ$ (fig. 13(a)) had a longitudinally stabilizing effect at all lift coefficients but was not powerful enough at lift coefficients below about 0.5 to eliminate the instability which occurred with tails off. The data of figures 13(a) and 14(a) show that adequate pitch control with and without the 30° single-slotted flap was provided up to a maximum lift coefficient by the horizontal-tail elevators. The lift increments produced by the 30°

single-slotted flap in conjunction with the deflected wing tip were substantial at the lower angles of attack although they tended to fall off near $(C_L)_{\max}$. The maximum trimmed lift coefficient obtained with the flap was about 15 percent higher than without the flap.

Lateral characteristics.- The yawing-moment coefficients for the pivoted-wing model were generally positive, with the largest positive yawing moments occurring at $\beta_w = 90^\circ$, and changes in lateral trim varied considerably with angle of attack (fig. 15). As for the fixed-wing model, the rolling-moment variation with angle of attack was very nonlinear at $\beta_w = 90^\circ$. Below an angle of attack of about 8° the magnitude of the rolling-moment coefficient generally increased as the wing sideslip angle was increased. At $\beta_w = 90^\circ$ there was a rapid decrease in rolling-moment coefficient from positive to negative values at an angle of attack of about 8° due to stall occurring near the apex of the wing similar to that described for the delta wing of reference 2. At wing sideslip angles lower than 90° , there were no significant nonlinearities due to stall occurring in the rolling-moment variation with angle of attack.

Because of the limited scope of this investigation, attempts at lateral control for the pivoted-wing model were confined to providing roll trim for the landing configuration and during a portion of the transition from high-speed configuration. The data of figures 16 and 17 show that trim for rolling moment could be provided over a fairly large angle of attack and wing sideslip angle range with the roll control used. Adding the 30° single-slotted flap at $\beta_w = 90^\circ$ (fig. 16(d)) produced a positive shift in the rolling-moment coefficient which enabled trim at higher angles of attack than without the flap (fig. 16(c)), but with this modification control stall at negative control deflections prevented roll trim at the lower angles of attack. Control effectiveness as measured by the rate of change of rolling-moment coefficient with control deflection (fig. 17) was not affected by changes in angle of attack, but as would be expected, decreased as the wing sideslip decreased from 90° .

Landing Considerations

The trimmed values of L/D for the pivoted-wing configuration given in figure 18 are values for which the model was trimmed in pitch and roll but not in yaw at a wing sideslip angle of 90° . The plot of glide angle as a function of flight speed presented in figure 19 is for a hypothetical pivoted-wing airplane of the type tested and is compared in this figure with that for the hypothetical arrow wing discussed in reference 1, both having a wing loading of 20 pounds per square foot. In order to illustrate the benefits to be gained in landing performance because of

the higher level of speed-altitude stability of the pivoted-wing airplane, flare-path computations similar to those discussed in reference 1 were made for the pivoted-wing configuration by using the method of reference 6. A sinusoidal variation of normal acceleration with a maximum normal acceleration of 1.75g was assumed in these computations for purposes of comparison, and the flight speed at the start of the flare was taken to be that for minimum glide angle. With these assumptions the lift coefficients used in the flare were within the range of values for which longitudinal and roll trim could be obtained. The results are compared with those from reference 1 in the following table and indicate considerably lower approach and touchdown speeds could be expected for pivoted-wing airplanes.

	Arrow wing (ref. 1)	Pivoted wing
Altitude at start of flare, ft	400 to 500	80 to 100
Flight speed at start of flare, knots . .	218	164
Flight speed at end of flare, knots . . .	173	90
Distance to complete flare, ft	3,200	407

As pointed out in reference 1, the ability of a pilot to control rate of sink is generally reduced as flight speed is reduced below that for minimum glide angle, and figure 20 indicates that control of steady-state rate of sink with either angle of attack or airplane attitude would also be difficult for the pivoted-wing configuration at minimum sinking speed. The minimum sink speed of the pivoted-wing configuration is considerably lower than that of the reference 1 configuration; however, the minimum rate of sink obtained (about 30 feet per second) is still higher than what is generally considered to be desirable for good altitude control in the landing approach.

SUMMARY OF RESULTS

An investigation has been made of a pivoted-arrow-wing model and of a fixed-arrow-wing model to determine the effects of either pivoting the wing on the fuselage to large angles of sideslip or yawing the complete model to large angles of sideslip to increase wing aspect ratio for improved landing performance. The results may be summarized as follows:

1. Sideslipping the fixed-wing model to large angles presented longitudinal and lateral stability and control problems and did not

provide sufficient aerodynamic improvement to warrant a consideration of this method of improving landing performance for the configuration tested.

2. The pivoted-wing arrangement appears to offer low-speed aerodynamic improvement for low-aspect-ratio configurations if longitudinal stability and control capabilities are provided and directional and roll control can be obtained.

3. With the wing pivoted to 90° sideslip, the pivoted-wing model with horizontal tails and elevators had static longitudinal stability except at the lower lift coefficients, and longitudinal trim was provided up to maximum lift coefficient.

4. Deflecting the apex portion of the wing provided roll control for only a limited angle-of-attack range with the wing pivoted 90° .

5. Calculations of the flare of a hypothetical pivoted-wing airplane indicate considerably lower values of landing speed and steady-state rate of sink than usually predicted for arrow-wing configurations. The minimum sink range obtained, however, was still higher than what is generally considered desirable.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., November 4, 1960.

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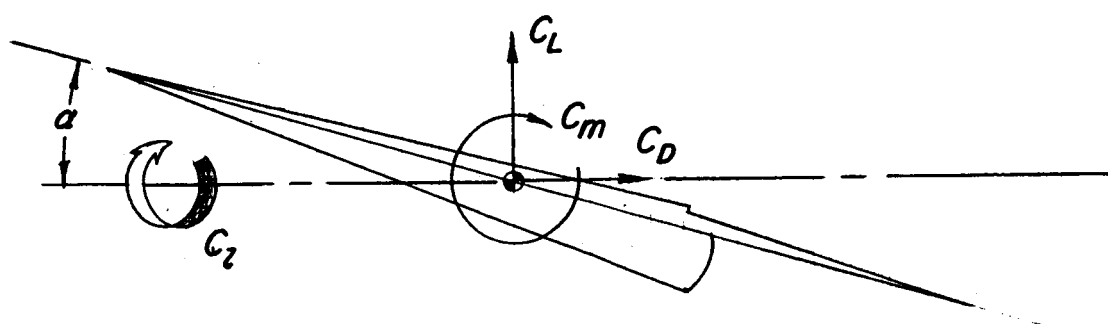
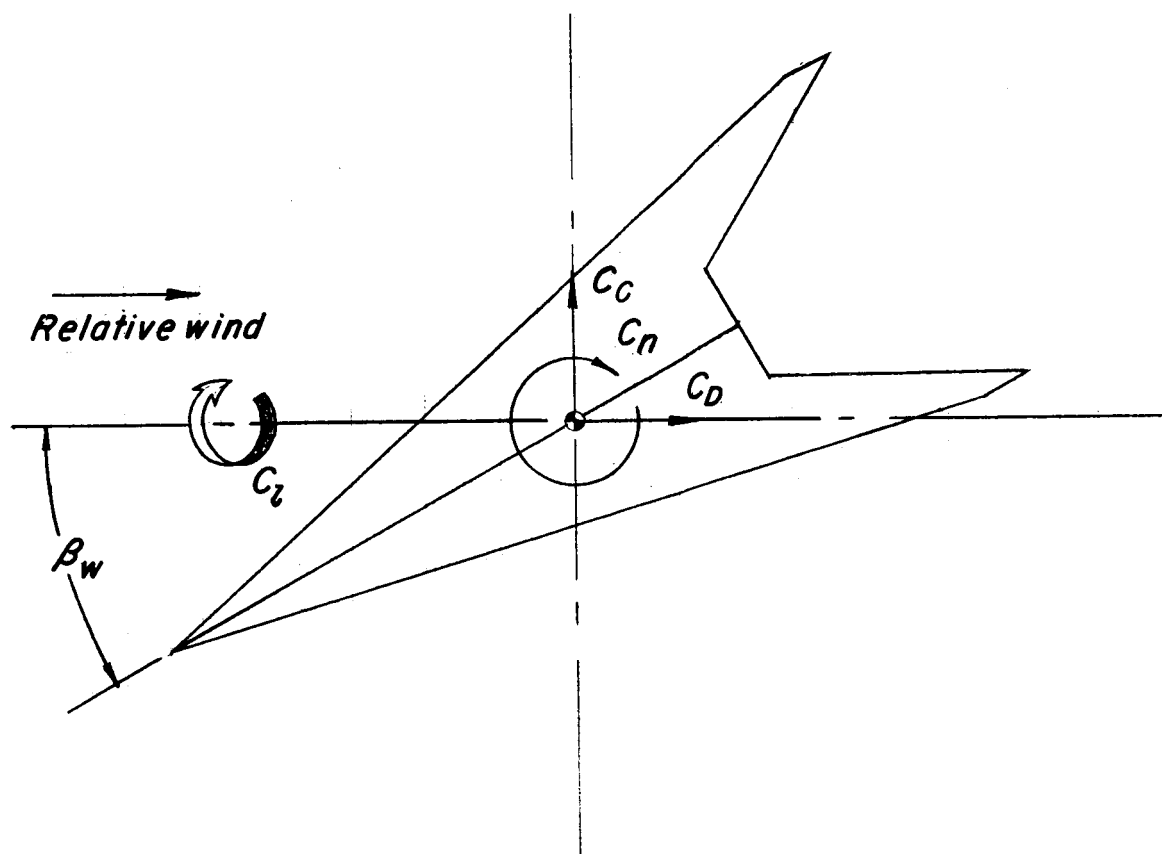
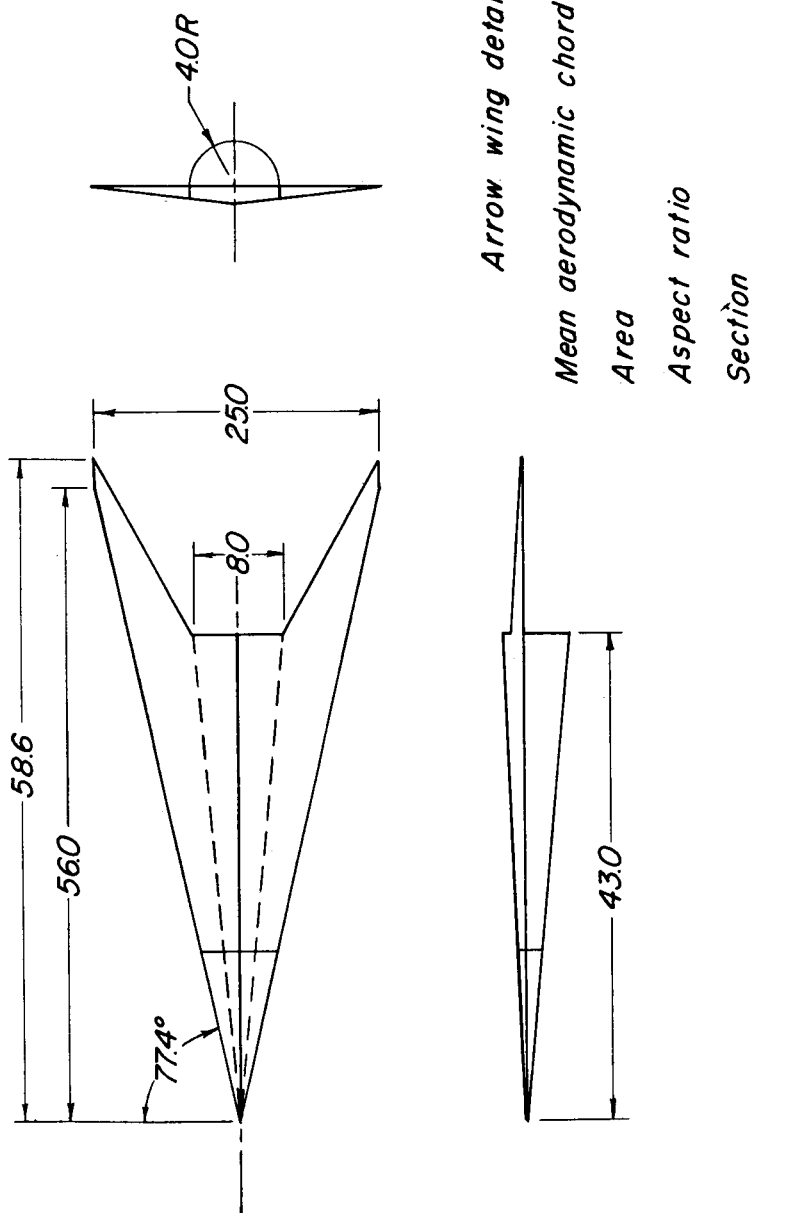
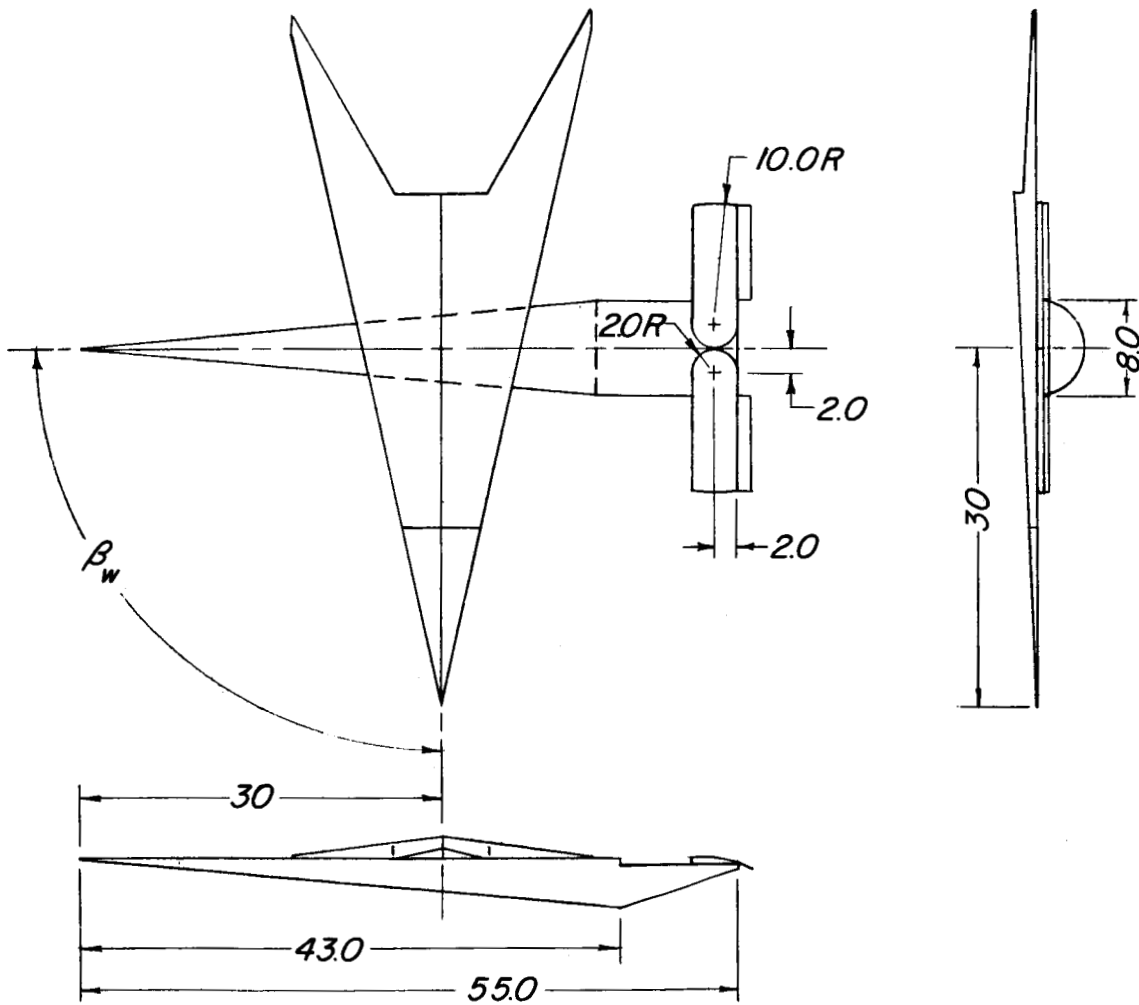


Figure 1.- Axes system and convention used to define positive sense of angles and coefficients of forces and moments.



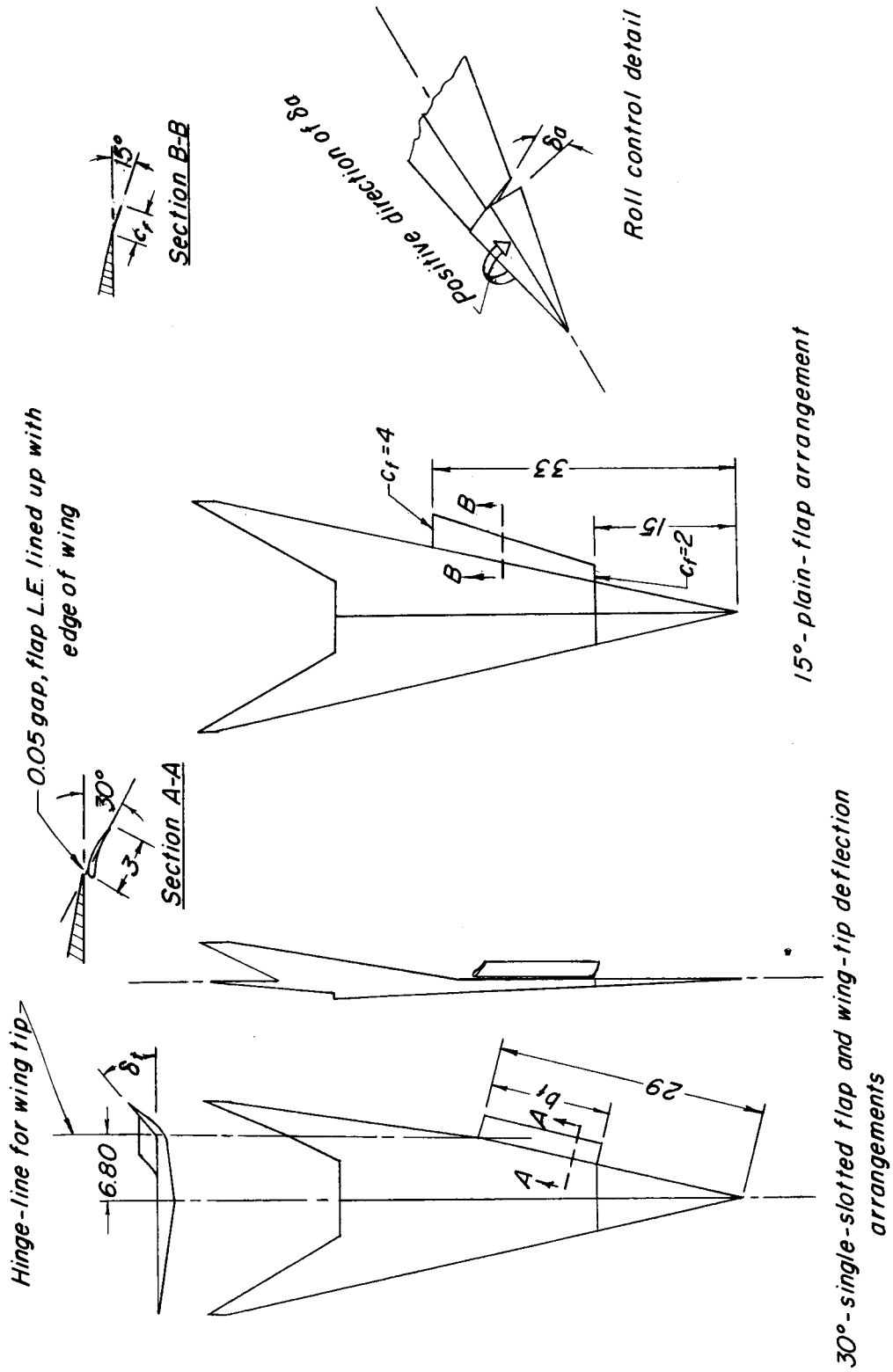
(a) Fixed-wing model.

Figure 2.- Geometric characteristics of the models. All dimensions in inches.



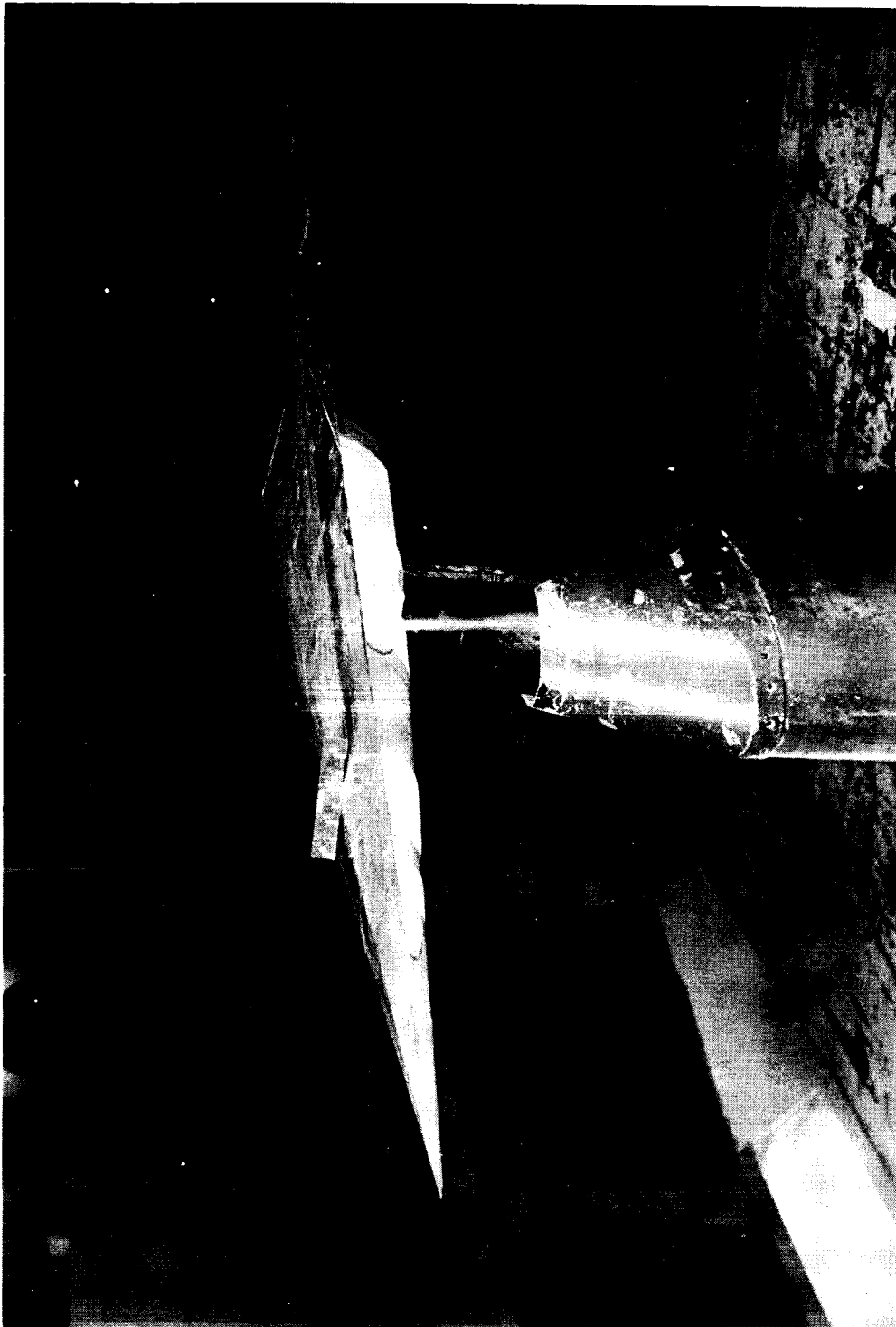
(b) Pivoted-wing model.

Figure 2.- Continued.



(c) Details of control and flap arrangements.

Figure 2.- Concluded.



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Figure 3.- Photograph of fixed-wing model in the 7- by 10-foot tunnel.

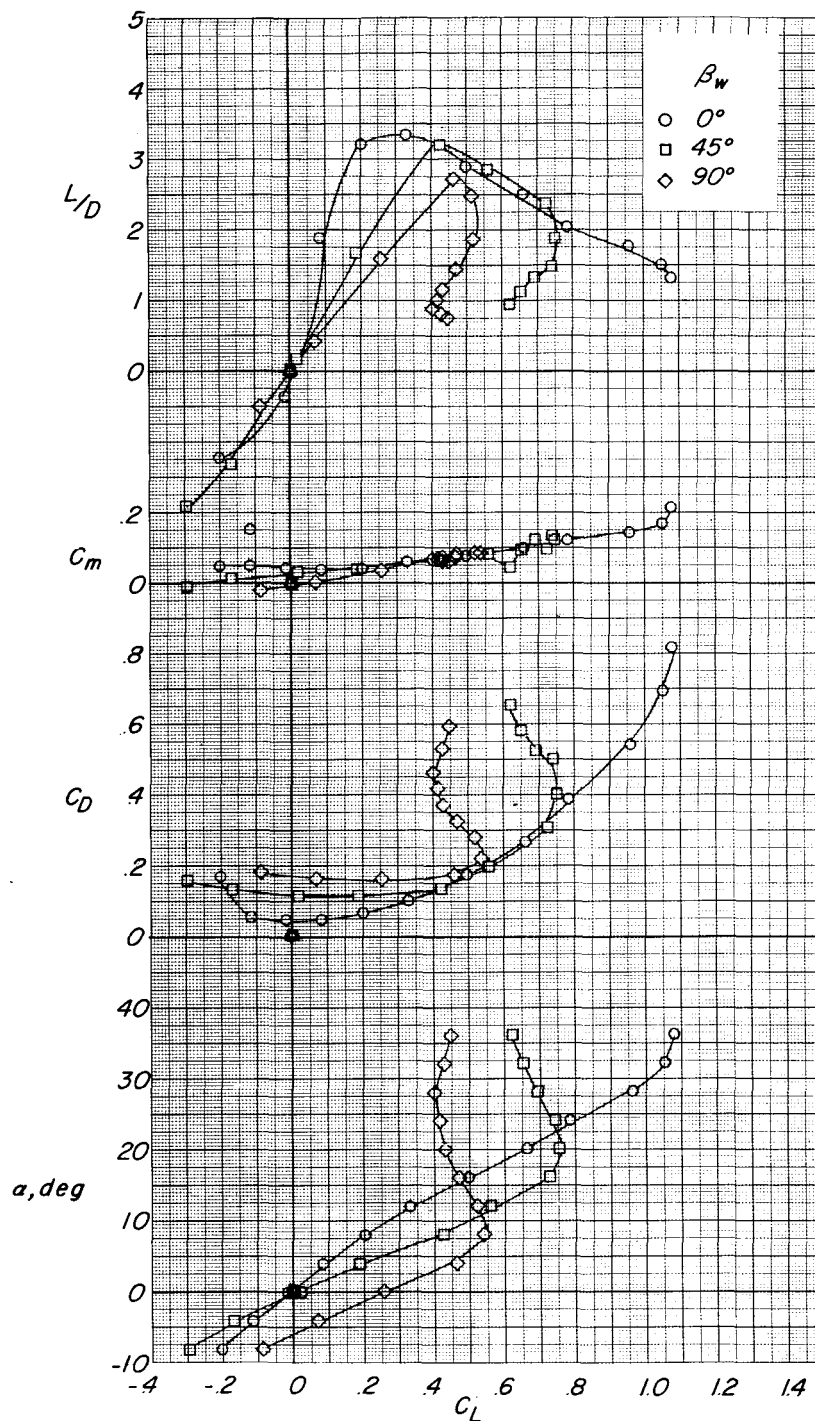


Figure 4.- Effects of sideslip angle on the longitudinal characteristics of the fixed-wing model.

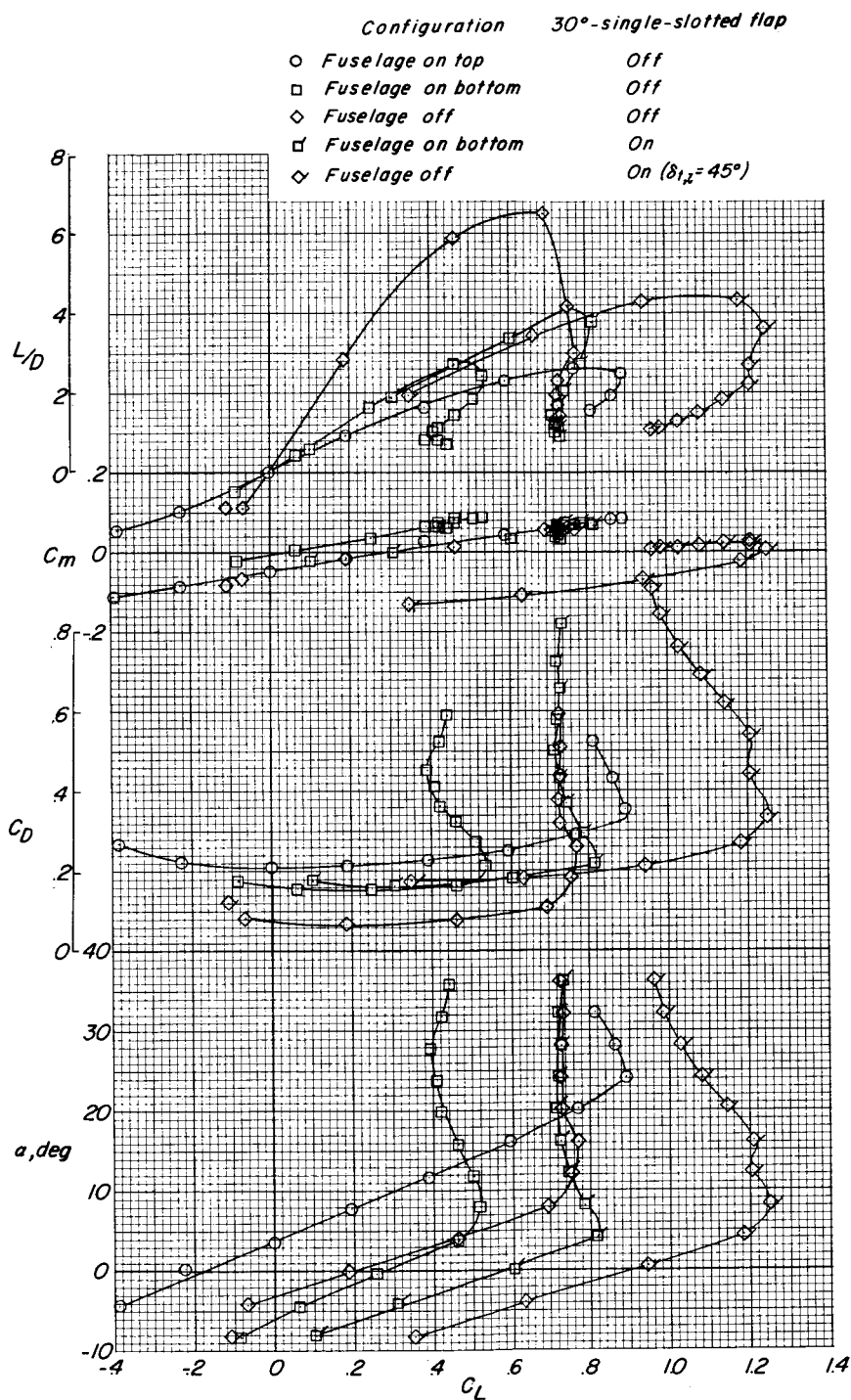


Figure 5.- Effects of modifications to the configuration on the longitudinal characteristics of the fixed-wing model. $\beta_w = 90^\circ$.

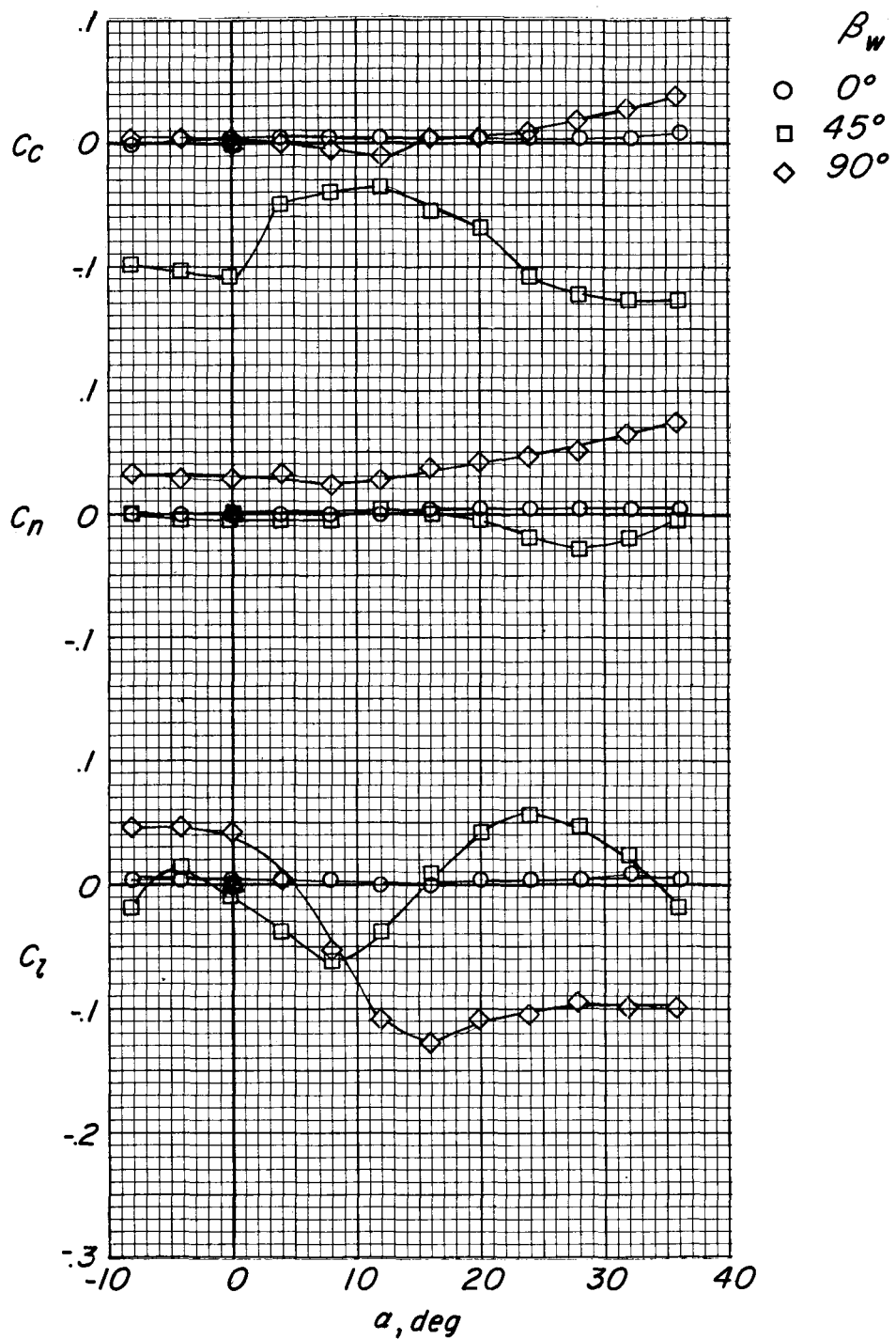


Figure 6.- Effects of sideslip angle on the lateral characteristics of the fixed-wing model.

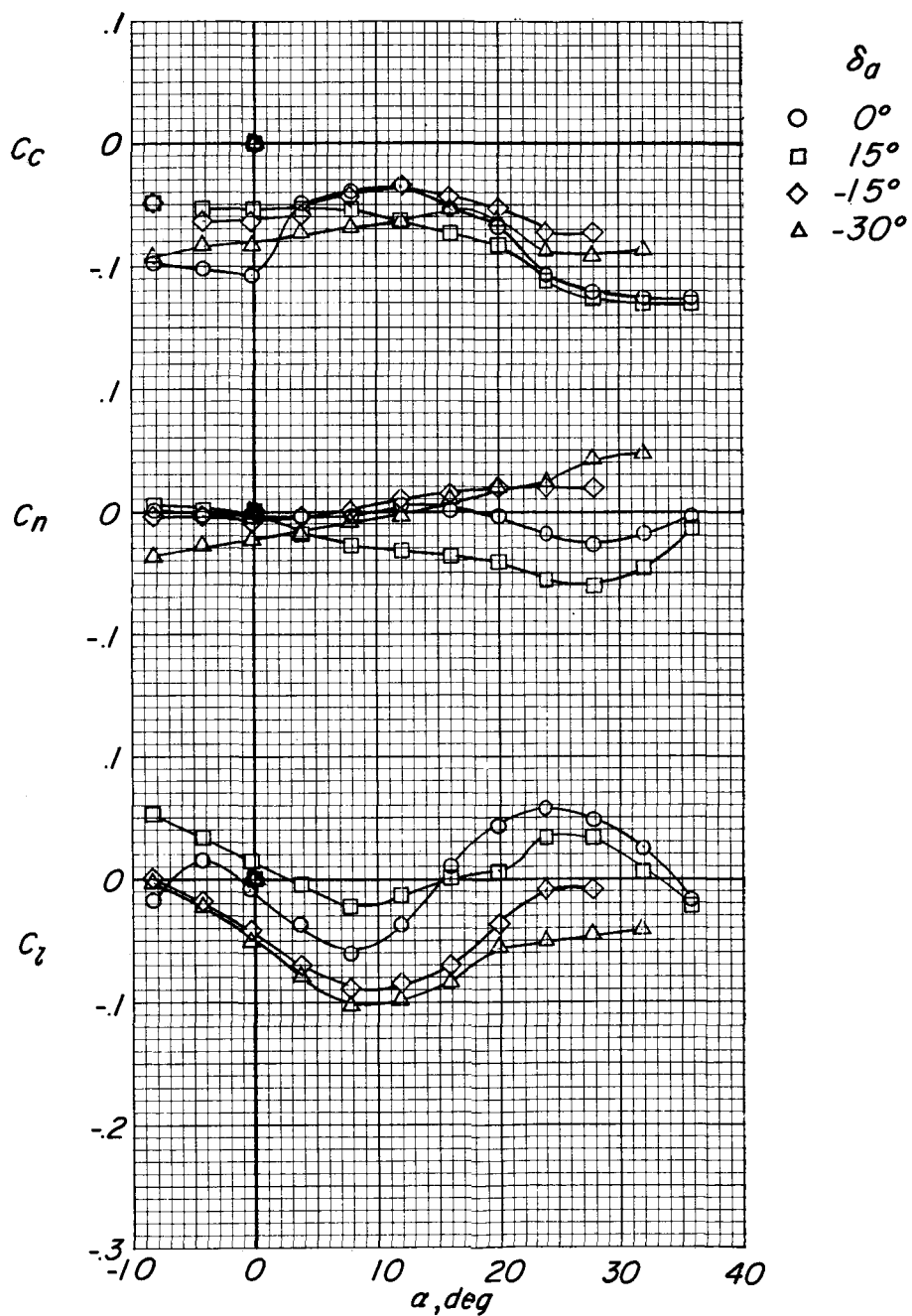
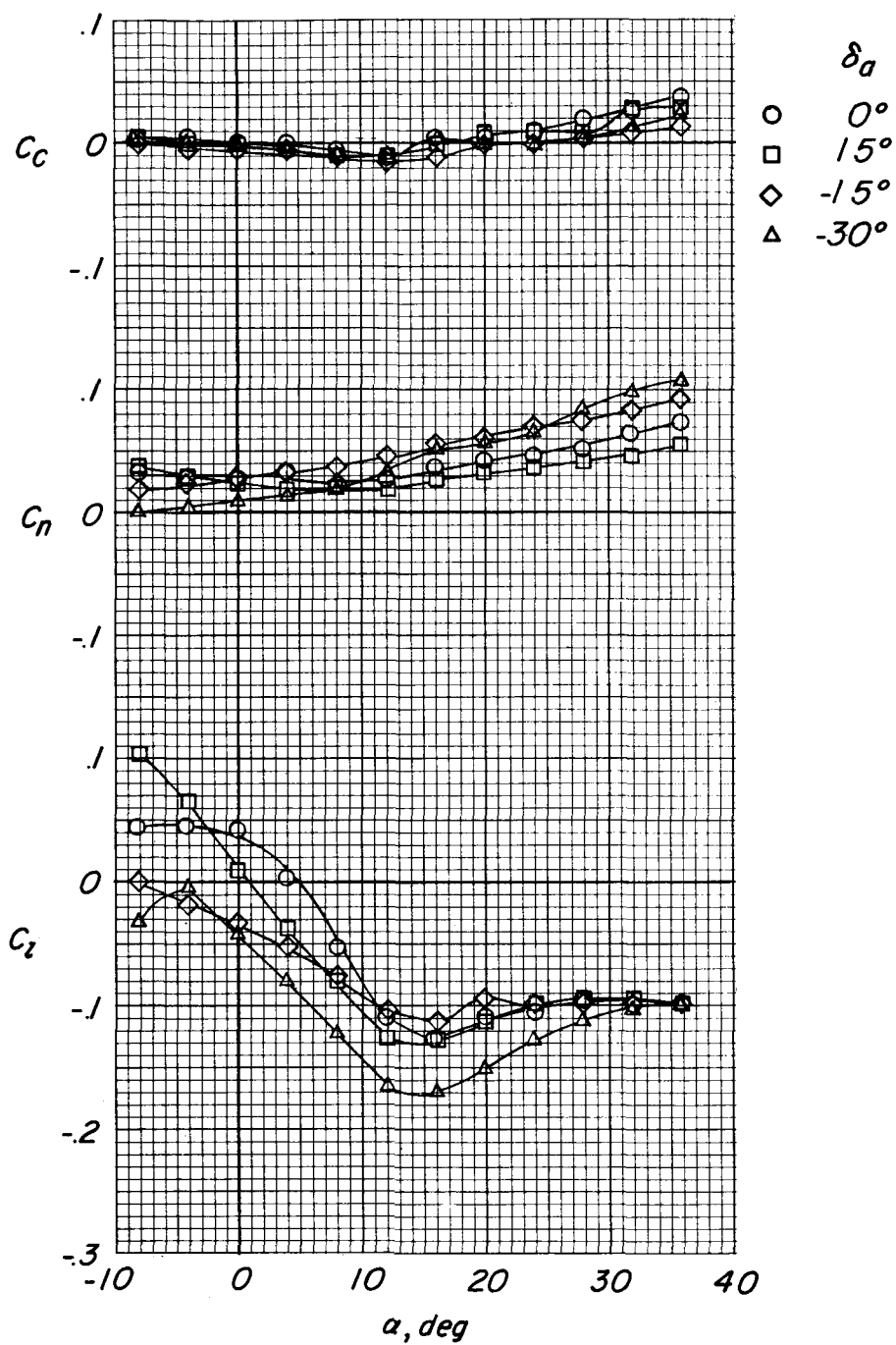
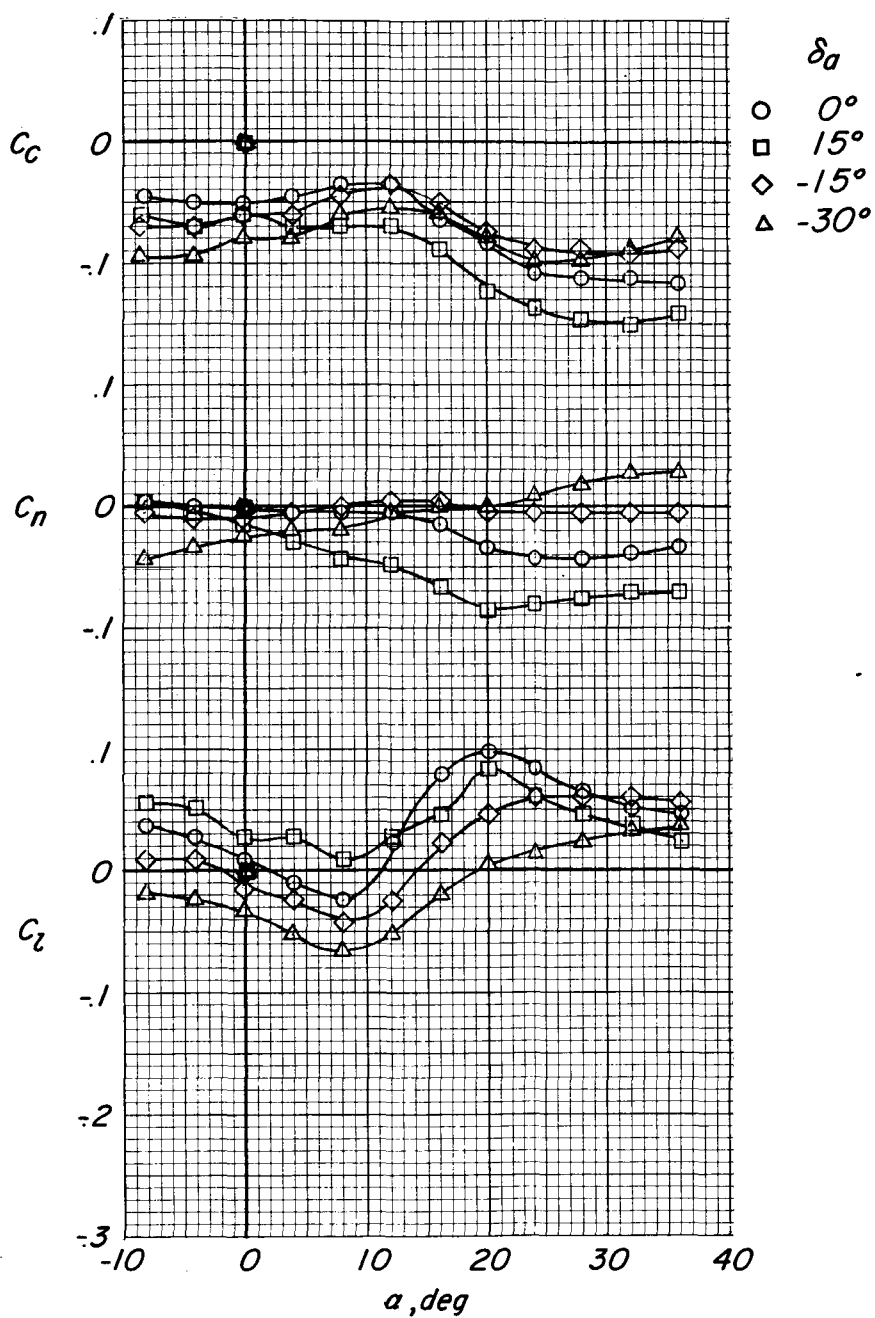
(a) $\beta_w = 45^\circ$.

Figure 7.- Effects of roll-control deflection on the lateral characteristics of the fixed-wing model.



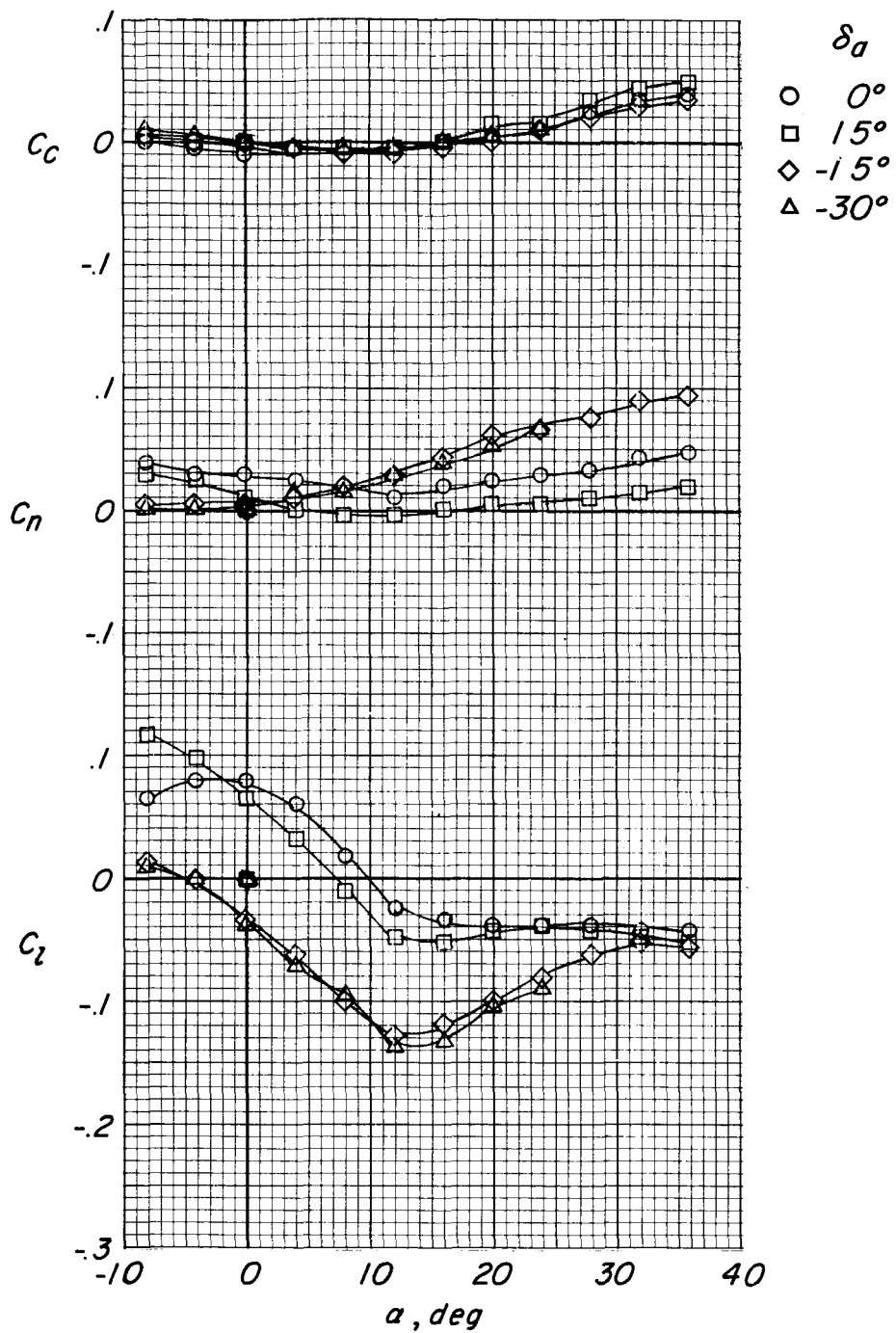
(b) $\beta_w = 90^\circ$.

Figure 7.- Concluded.



(a) $\beta_w = 45^\circ$.

Figure 8.- Effects of roll-control deflection on the lateral characteristics of the fixed-wing model with 15° plain flap on.



(b) $\beta_w = 90^\circ$.

Figure 8.- Concluded.

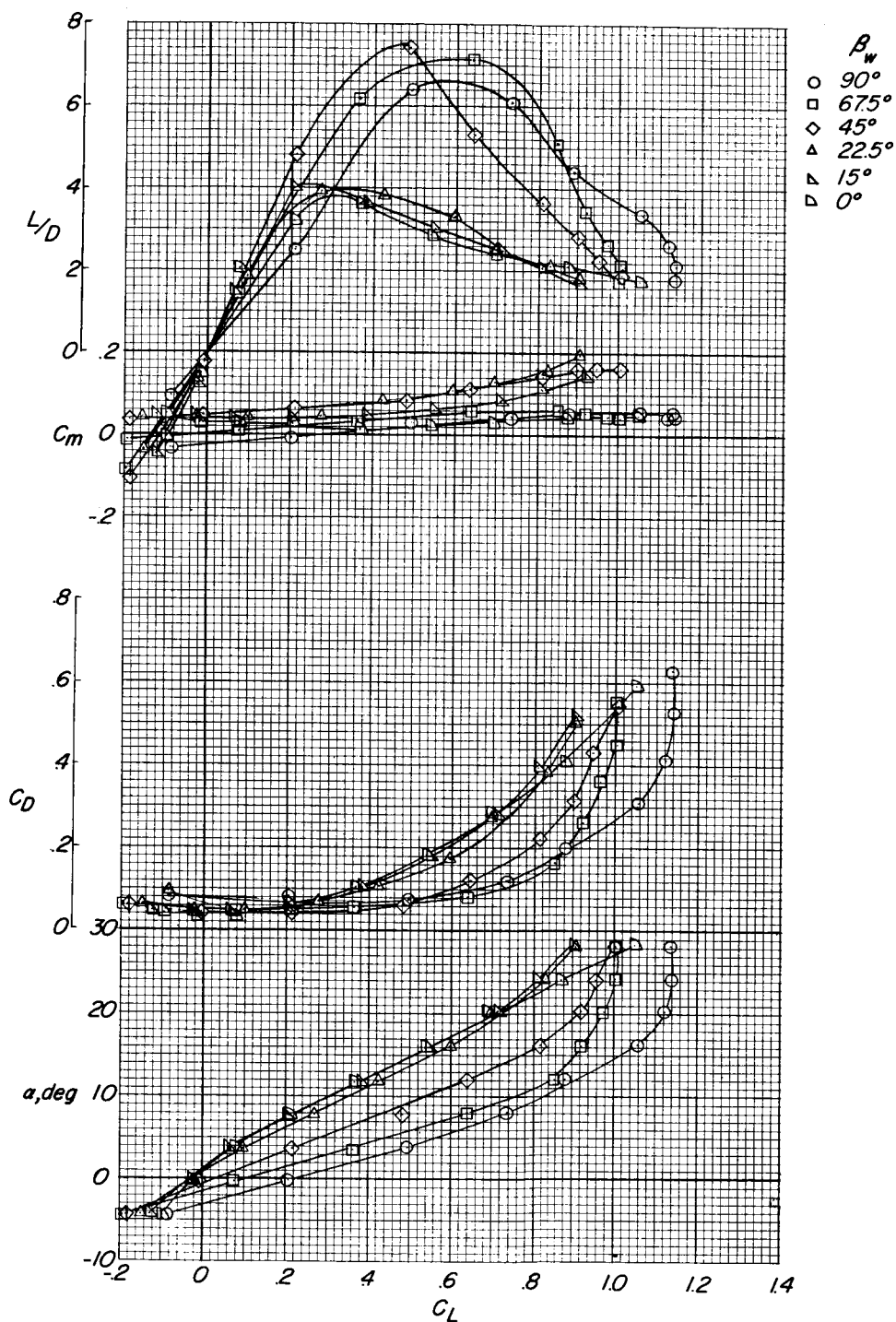


Figure 9.- Effect of wing sideslip angle on the longitudinal characteristics of the pivoted-wing model. Horizontal tails off.

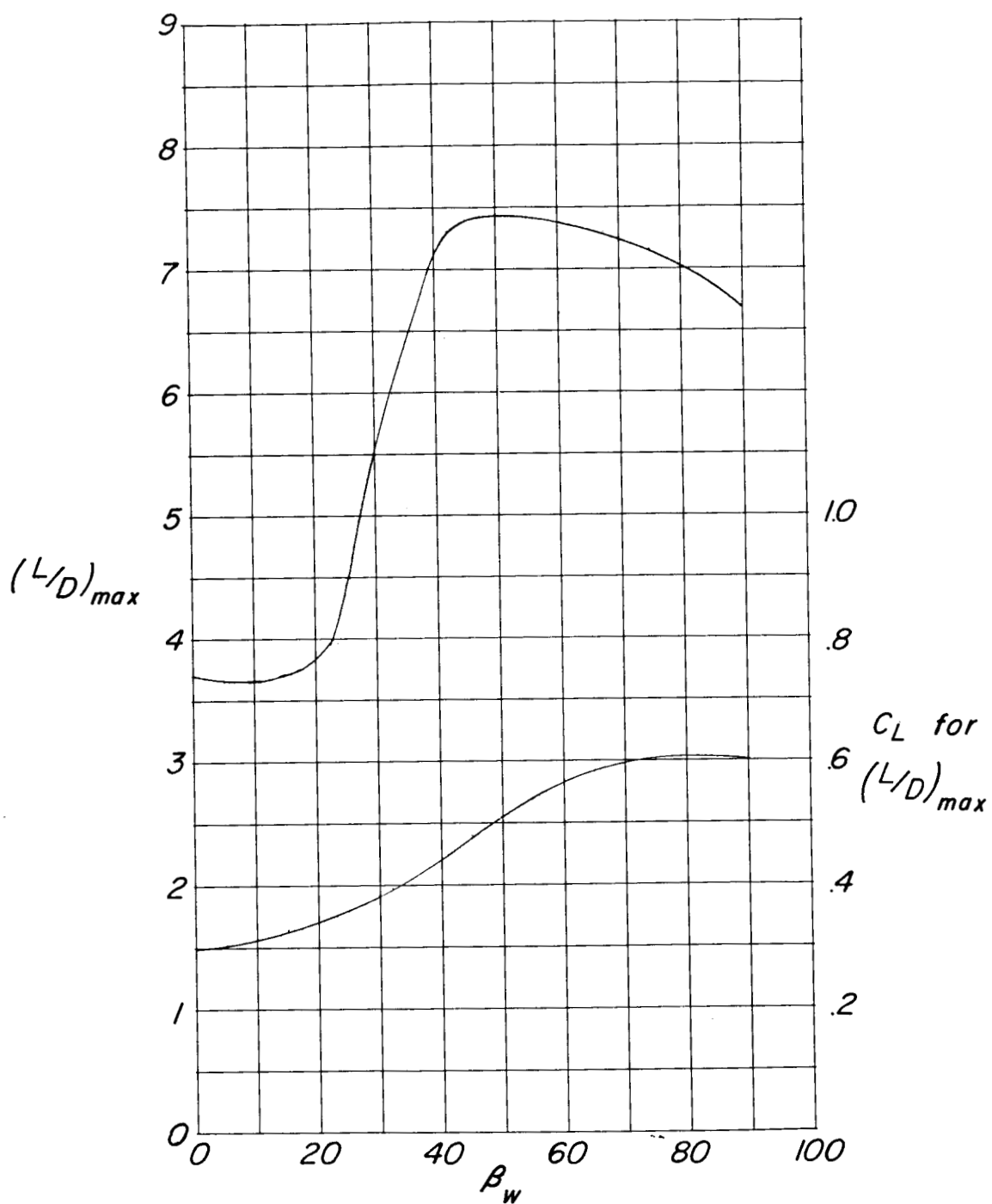


Figure 10.- Maximum L/D and the lift coefficient for maximum L/D as a function of wing sideslip angle. Horizontal tails off.

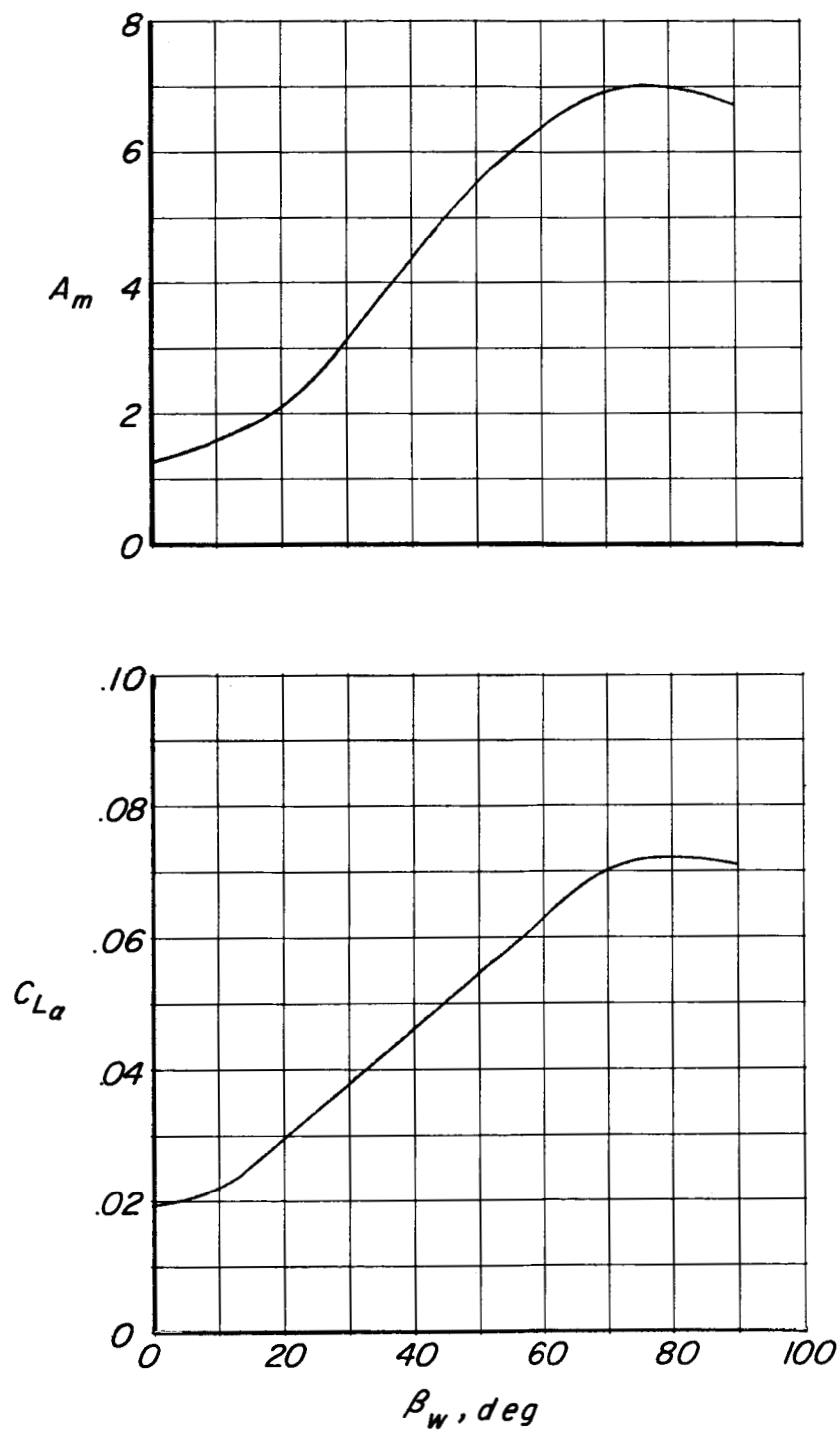


Figure 11.- Modified wing aspect ratio and lift-curve slope as functions of wing sideslip angle.

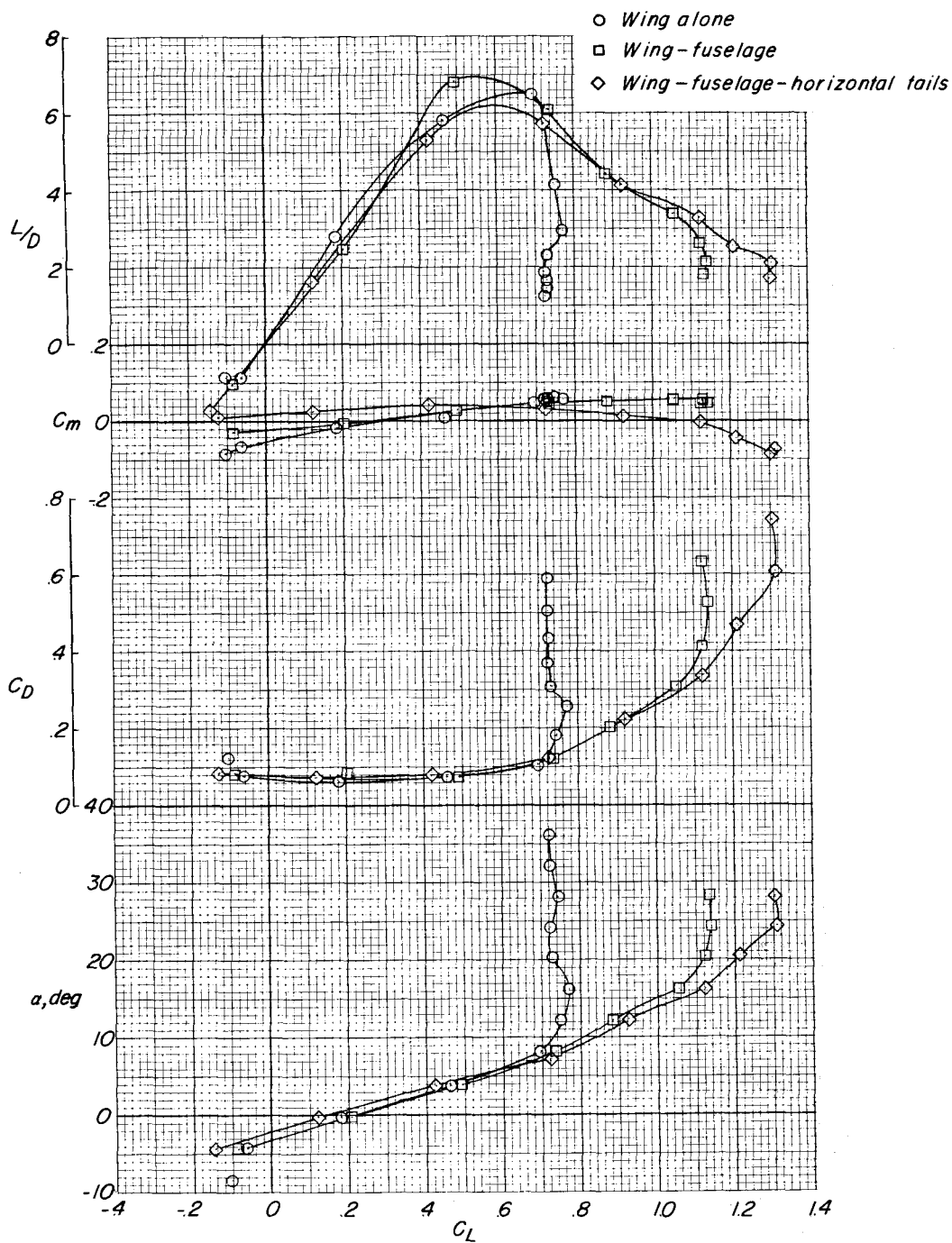
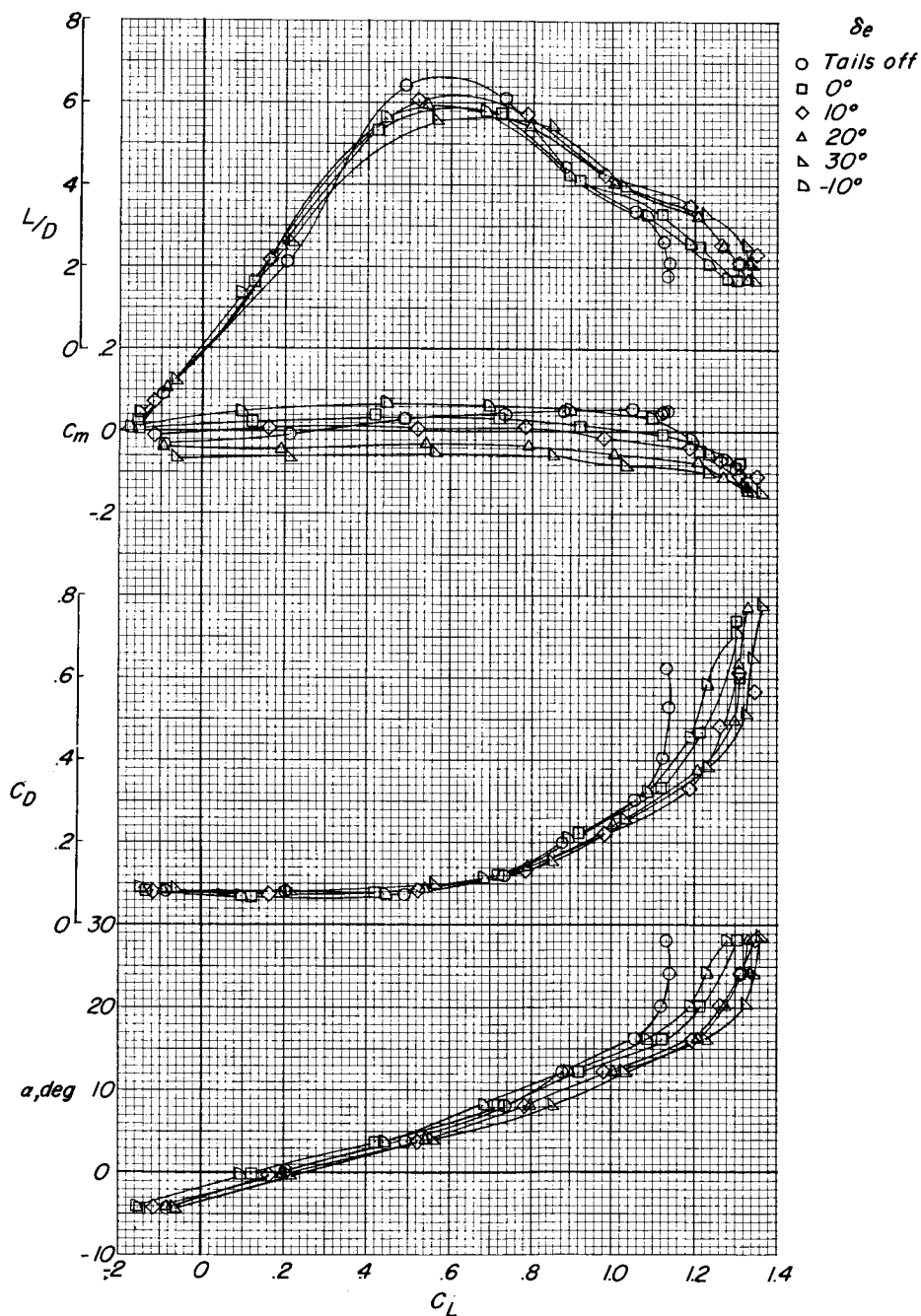
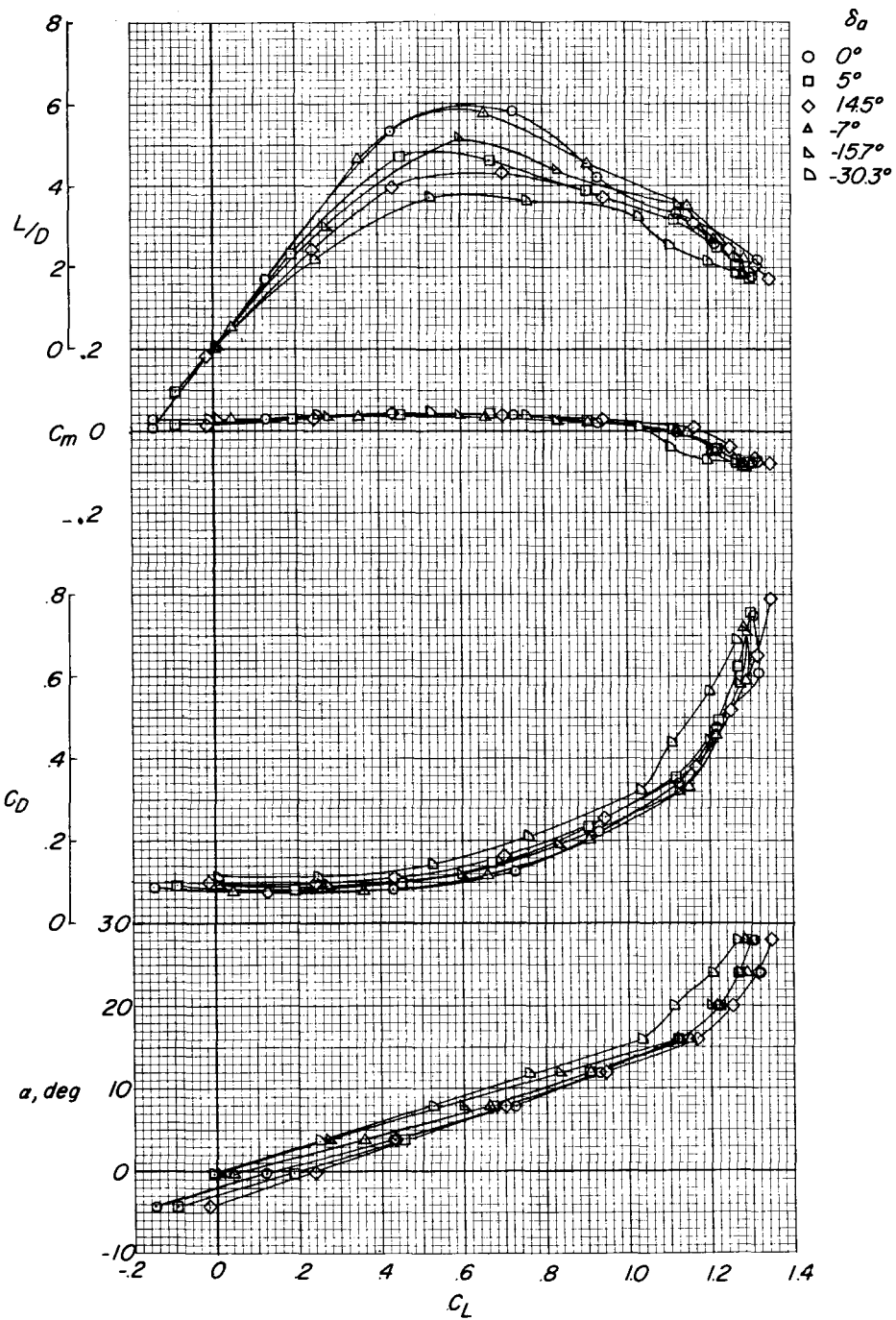


Figure 12.- Contributions of the wing, fuselage, and horizontal tails to the lift, drag, and pitching moment of the pivoted-wing model.
 $\beta_w = 90^\circ$.



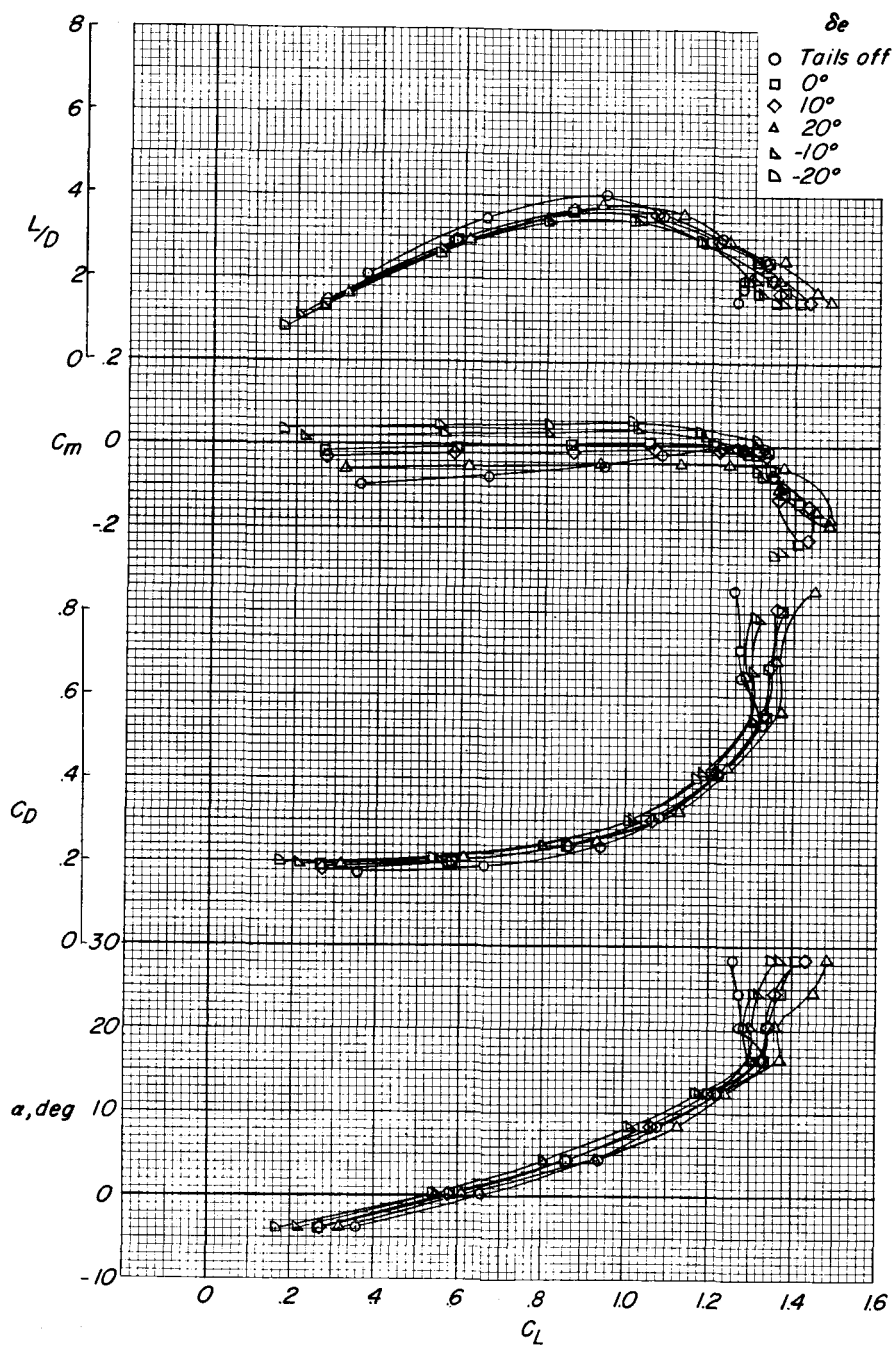
(a) Effects of elevator deflection.

Figure 13.- Longitudinal characteristics of the pivoted-wing model with 90° wing sideslip angle. Flap off.



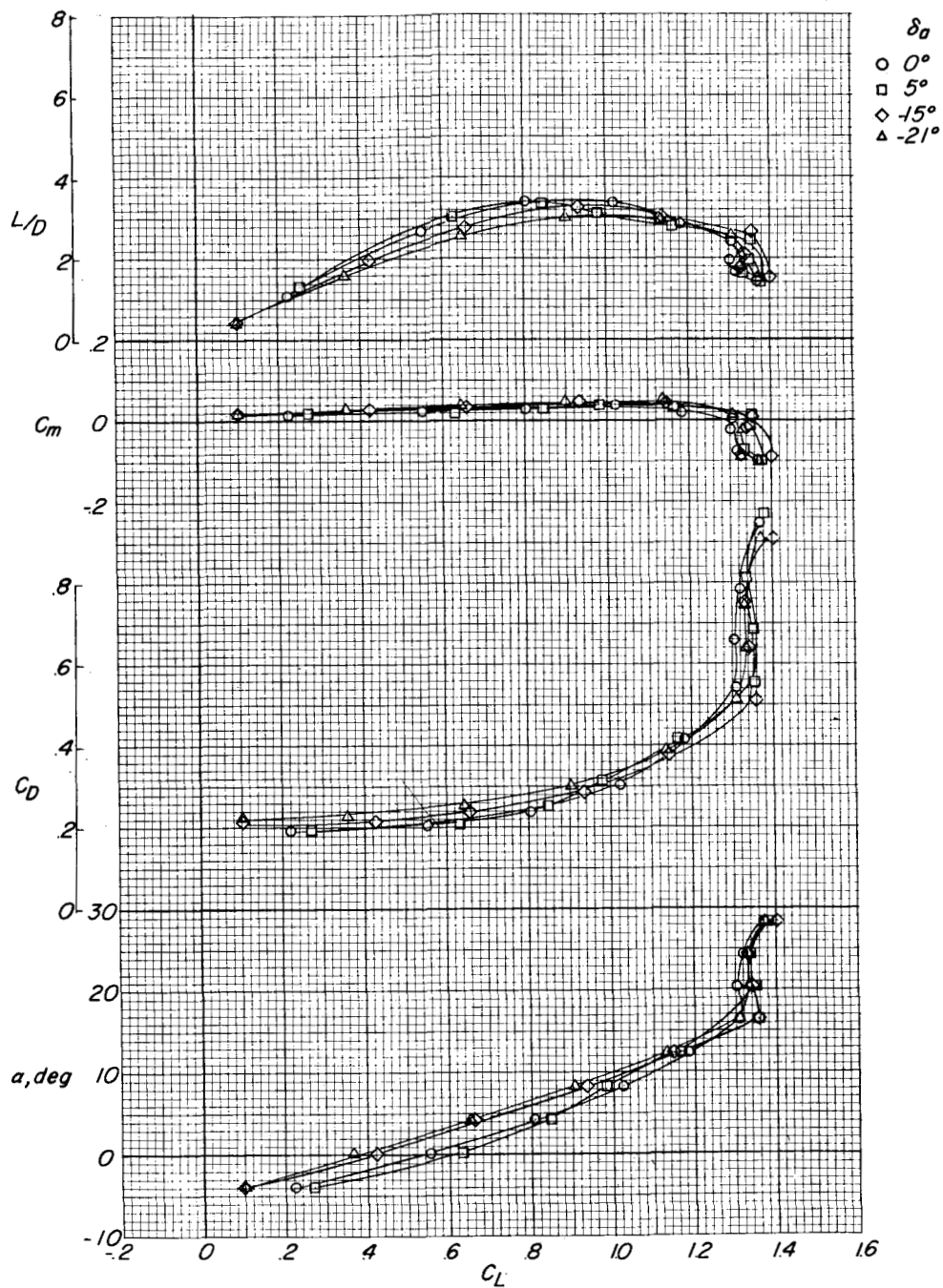
(b) Effects of roll-control deflection.

Figure 13.- Concluded.



(a) Effects of elevator deflection.

Figure 14.- Longitudinal characteristics of the pivoted-wing model with 90° wing sideslip angle. 30° single-slotted flap on.



(b) Effects of roll-control deflection.

Figure 14.- Concluded.

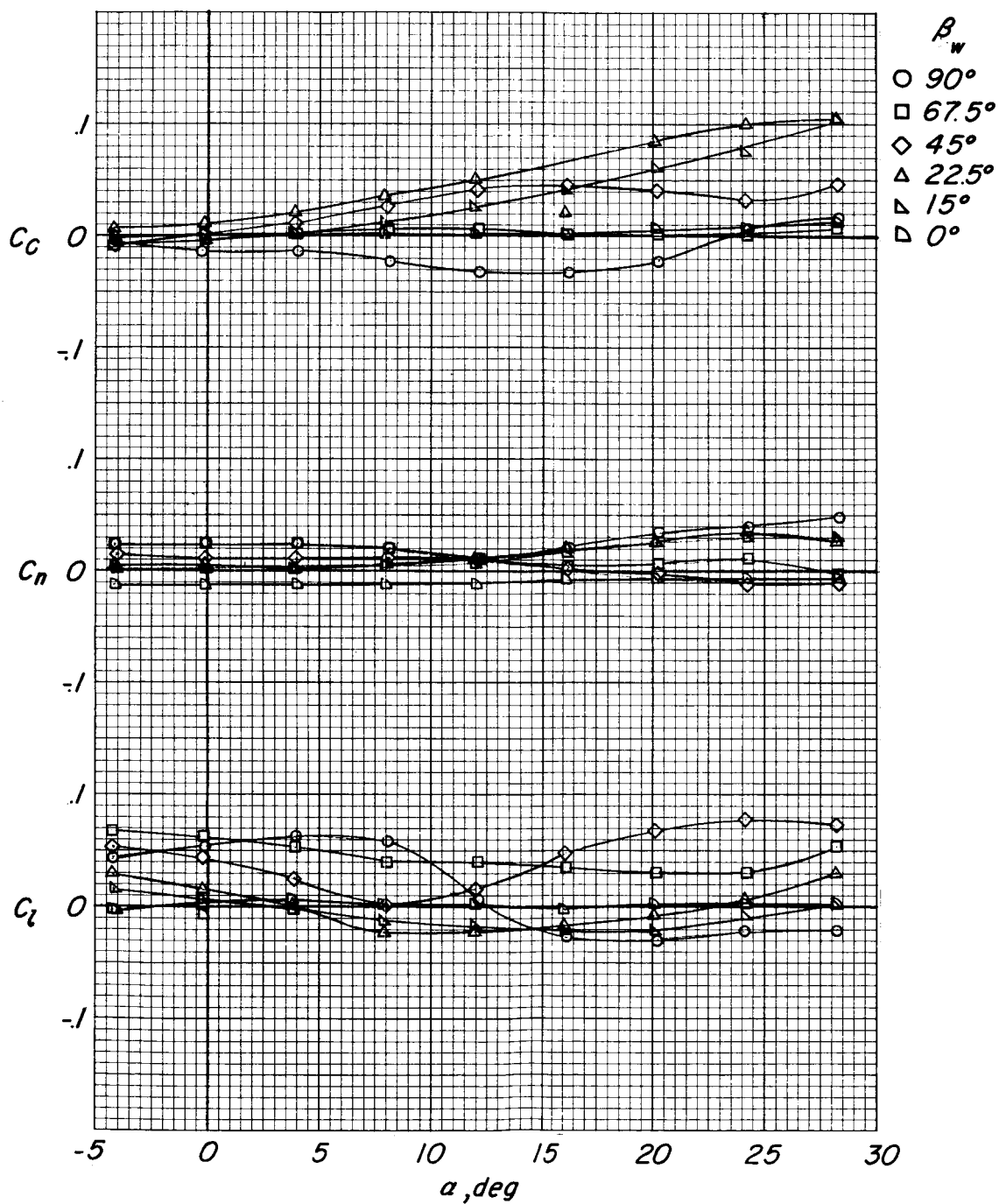
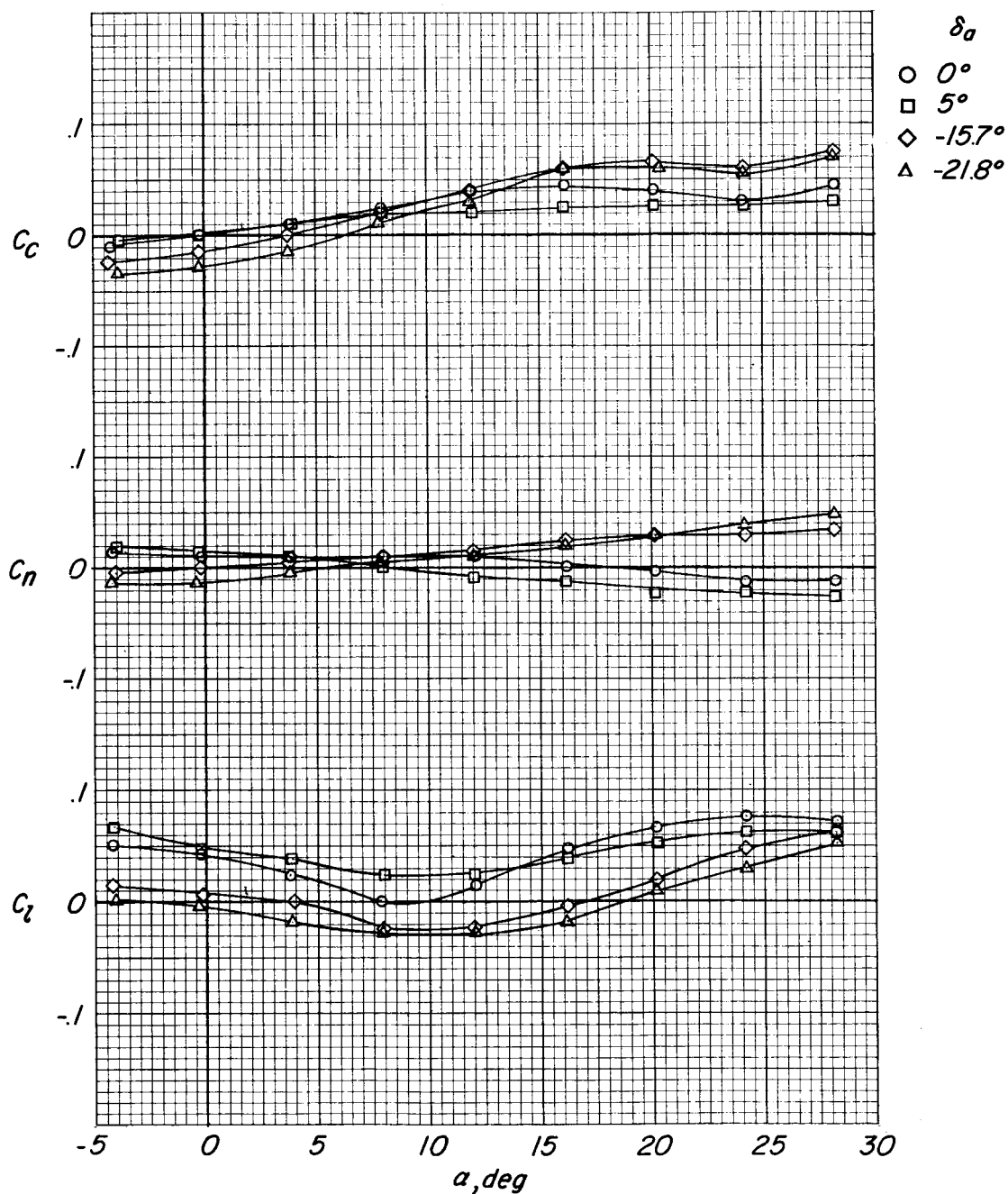
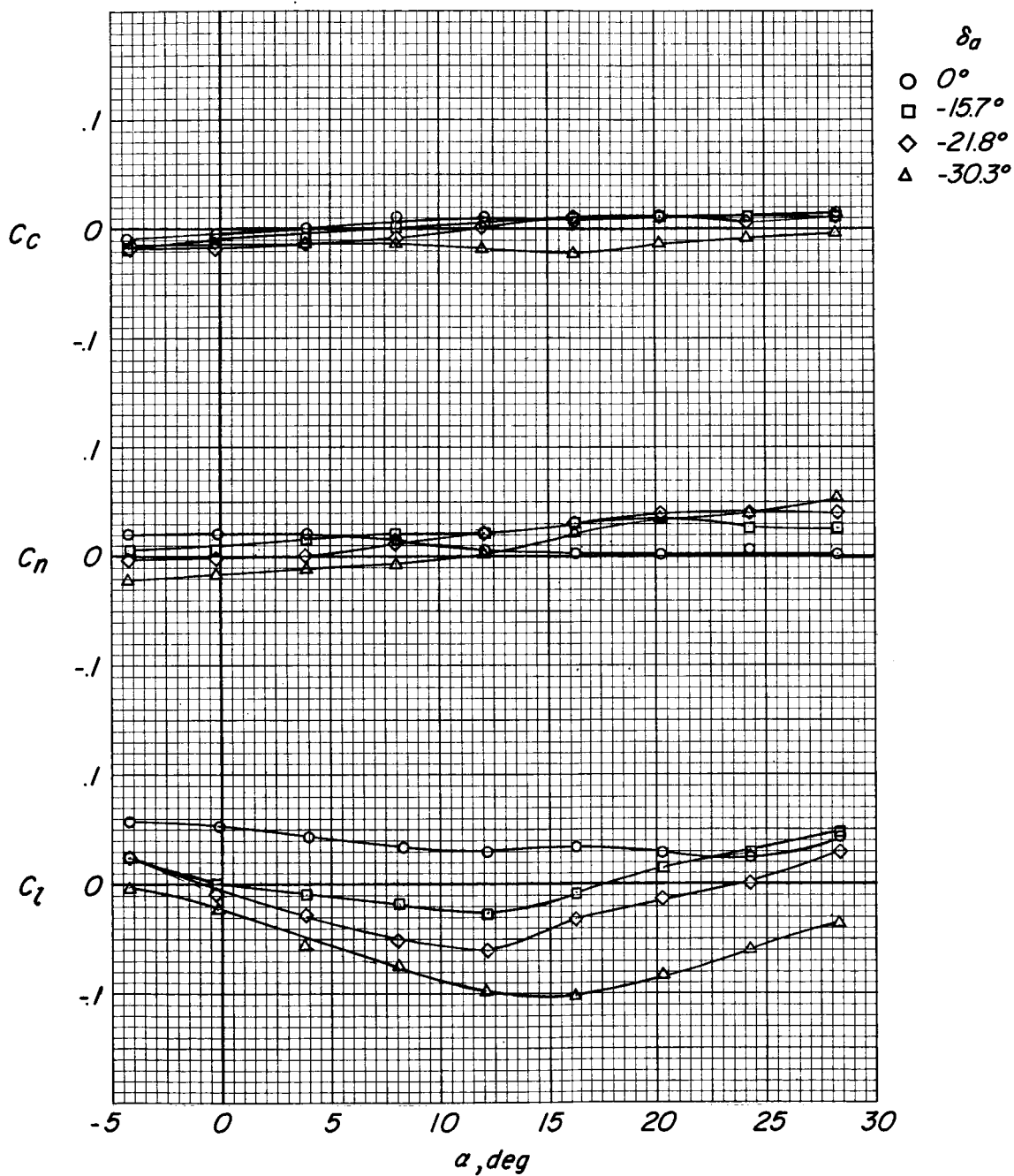


Figure 15.- Effects of wing sideslip angle on the lateral characteristics of the pivoted-wing model.



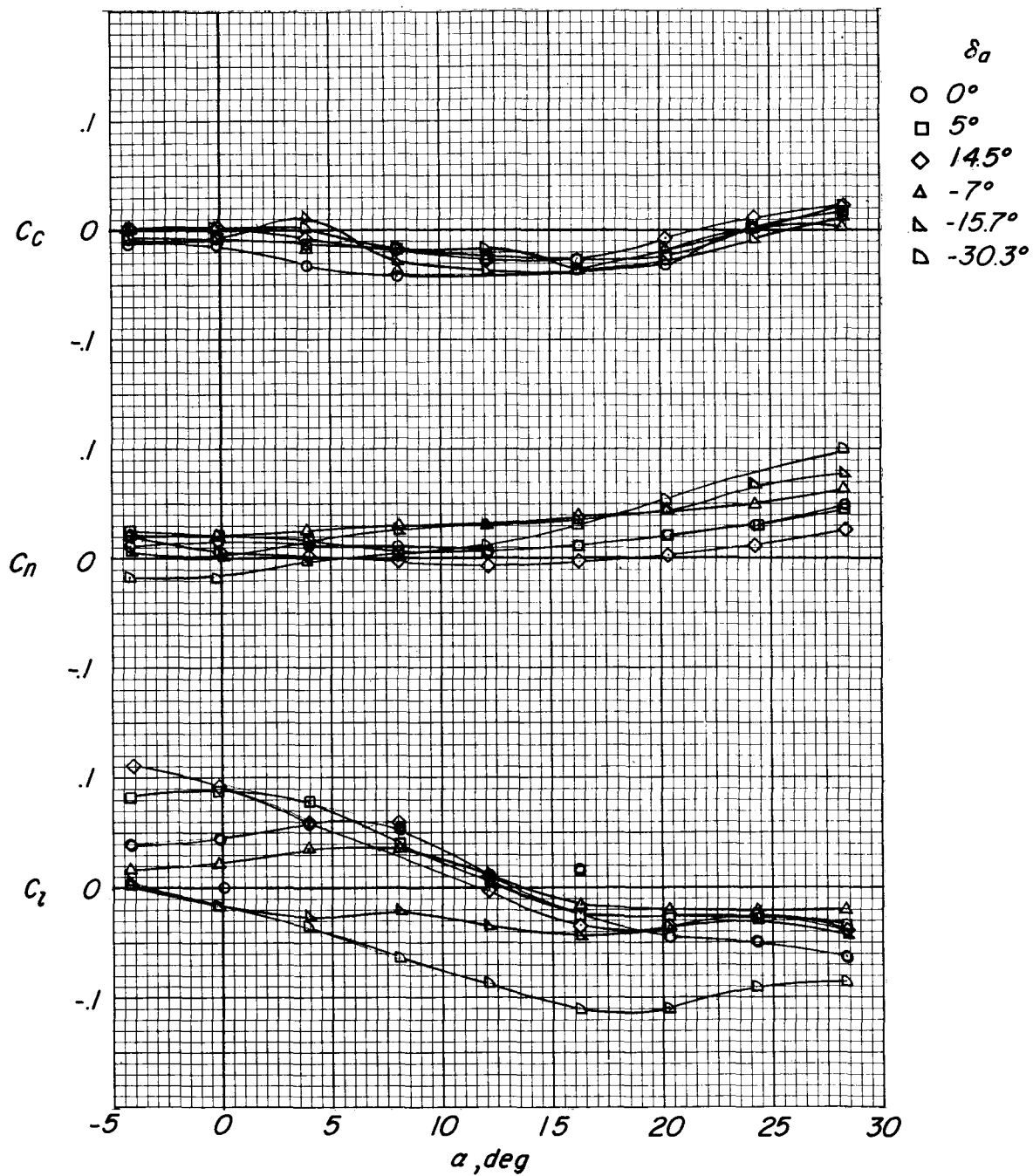
(a) $\beta_w = 45^\circ$.

Figure 16.- Effects of roll-control deflection on the lateral characteristics of the pivoted-wing model at various wing sideslip angles.



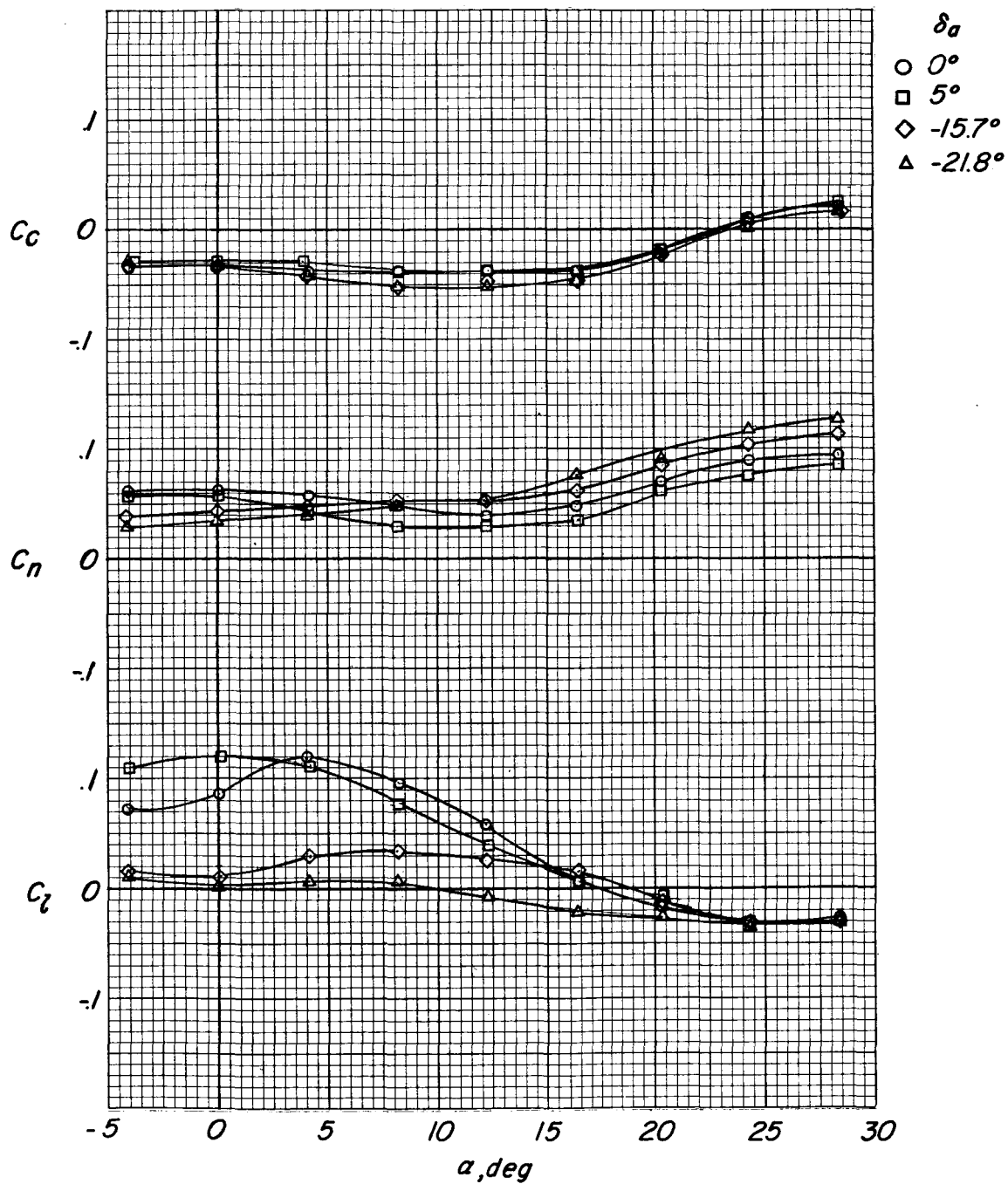
(b) $\beta_w = 67.5^\circ$.

Figure 16.- Continued.



(c) $\beta_w = 90^\circ$.

Figure 16.- Continued.



(d) $\beta_w = 90^\circ$ with 30° single-slotted flap on. $\delta_{t,l} = 45^\circ$.

Figure 16.- Concluded.

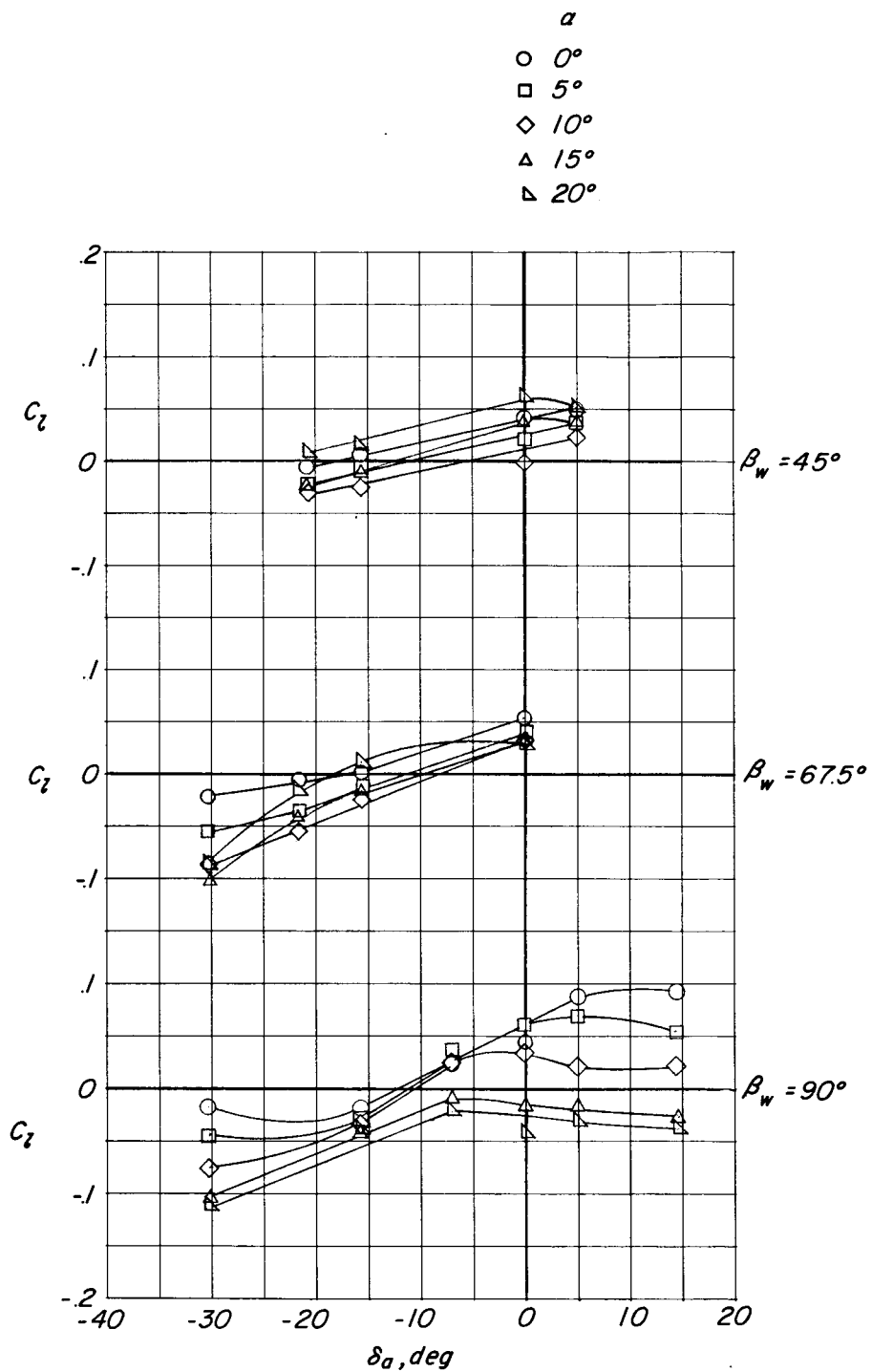


Figure 17.- Variation of rolling-moment coefficient with roll-control deflection for the pivoted-wing model.

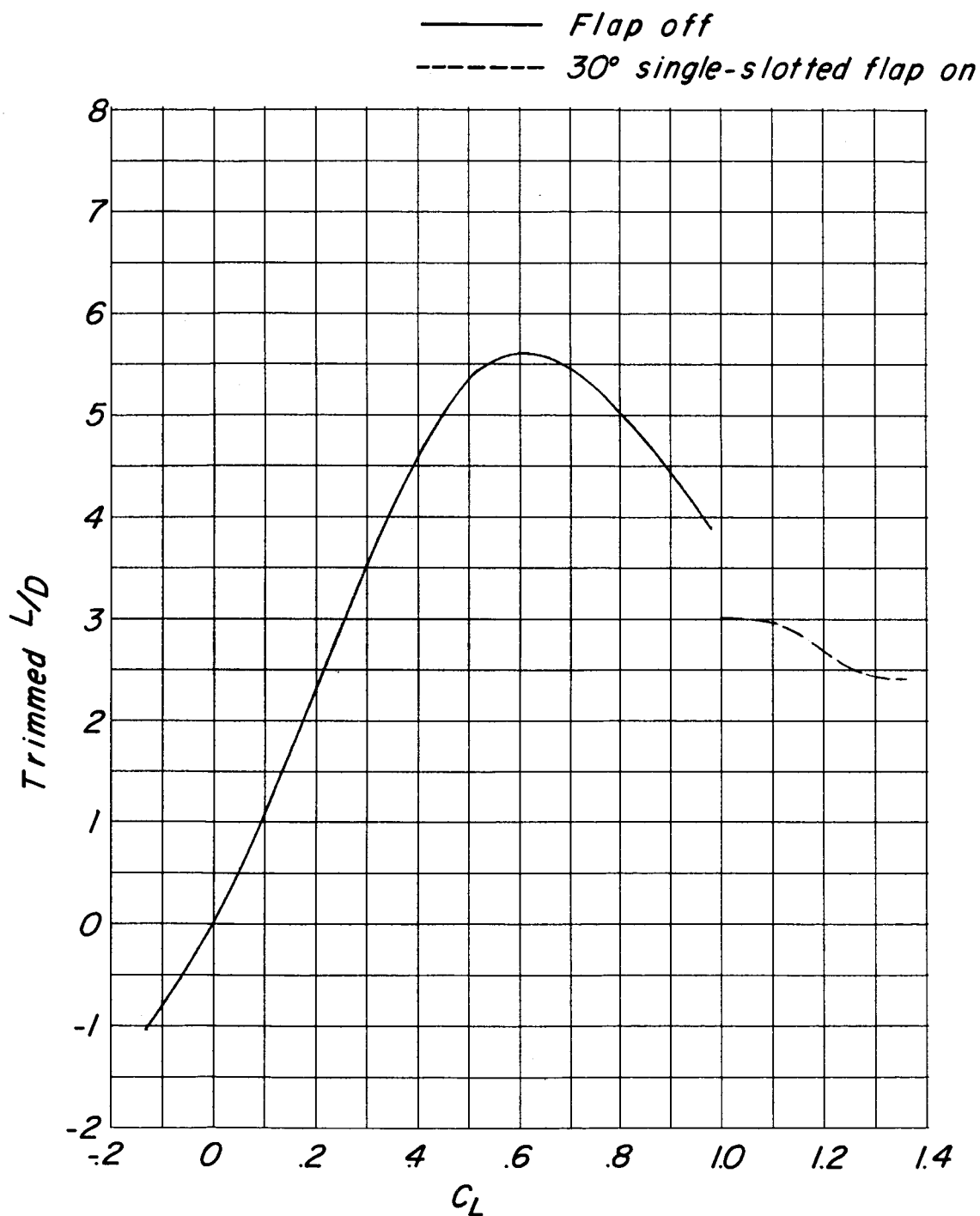


Figure 18.- Trimmed values of lift coefficient and L/D for the pivoted-wing configuration with 90° wing sideslip angle.

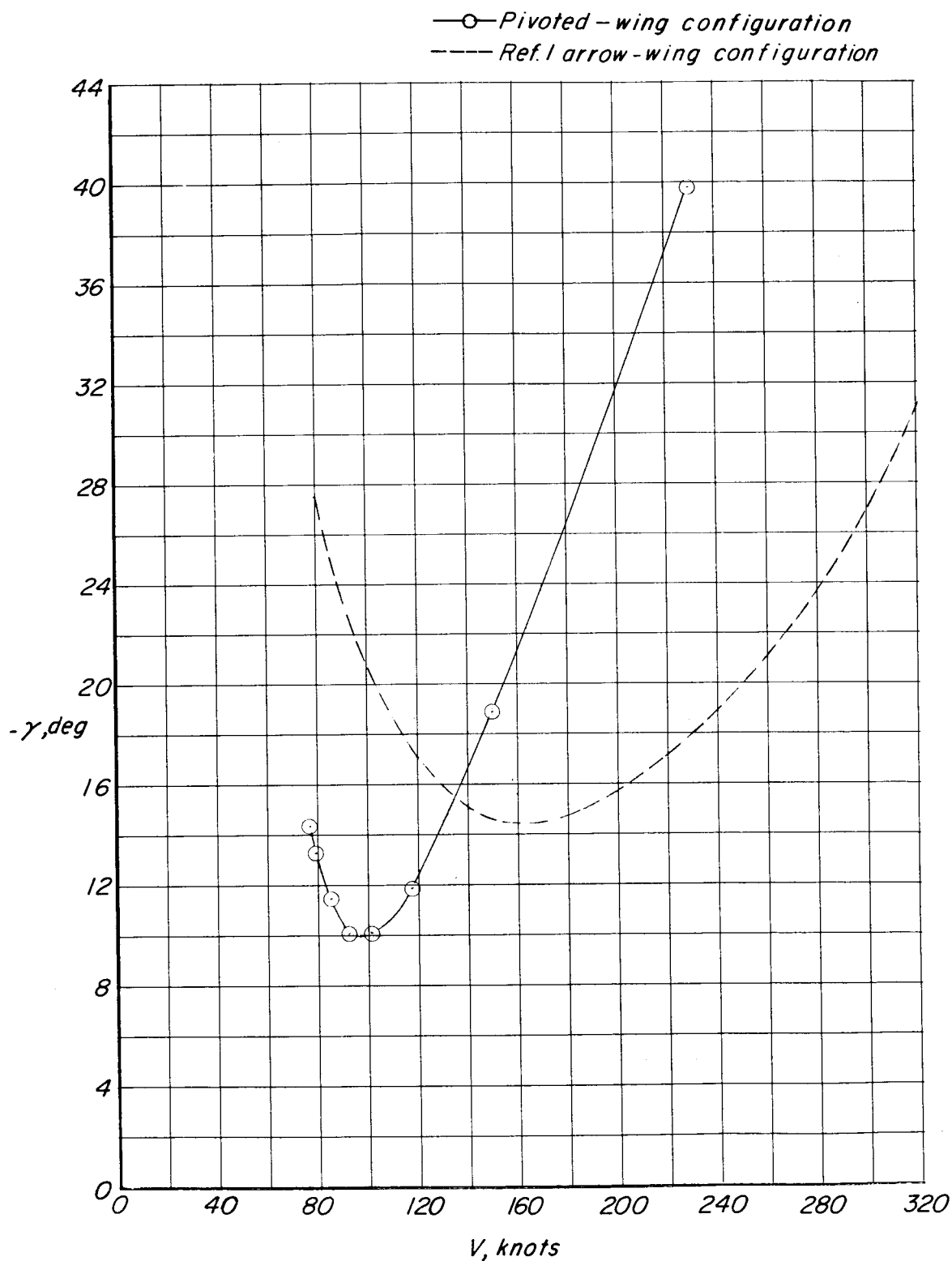


Figure 19.- Variation of power-off glide angle with flight speed for unaccelerated flight. $W/S = 20$ lb/sq ft.

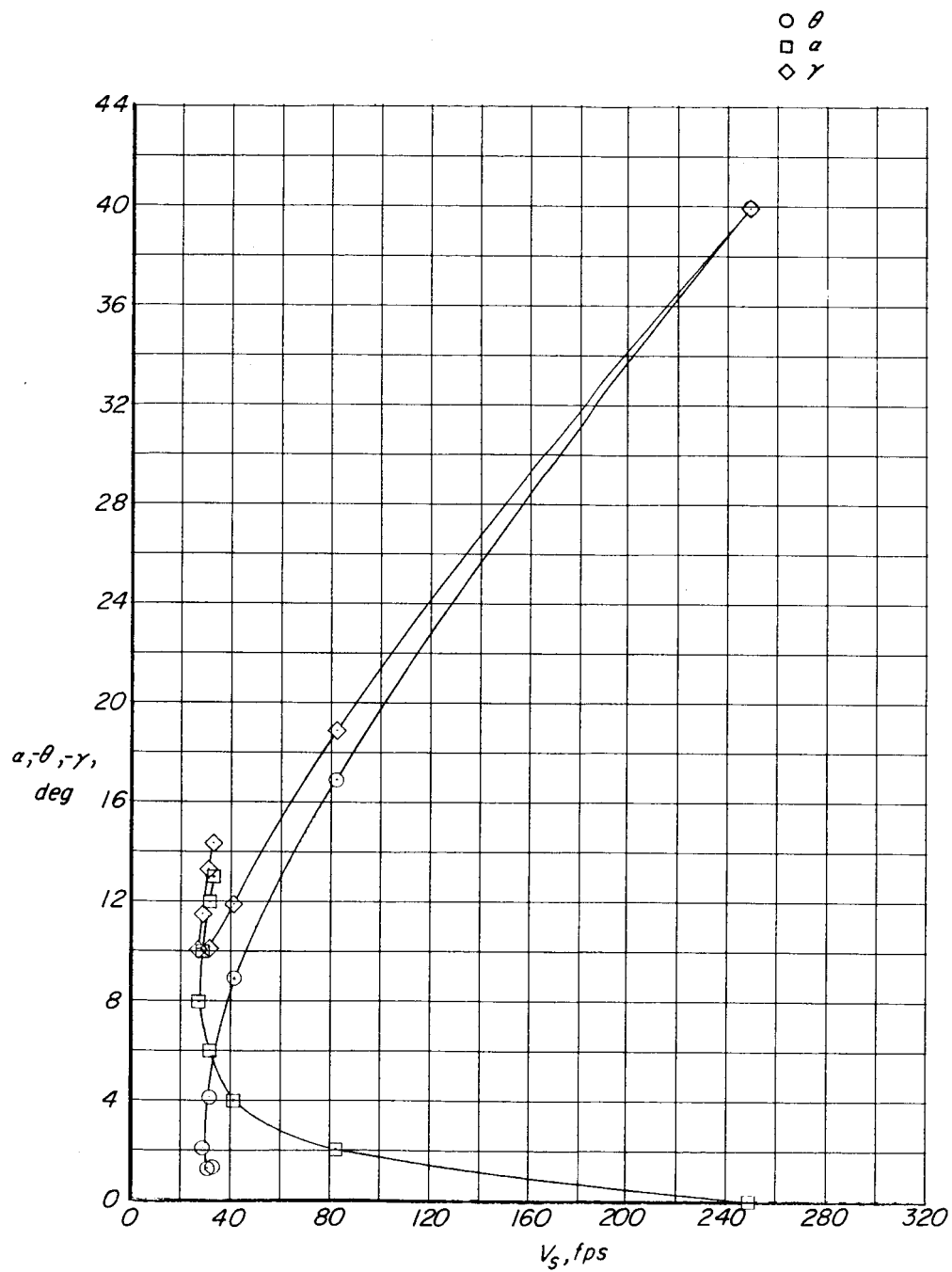


Figure 20.- Variation of angle of attack, glide angle, and attitude angle with sinking speed for unaccelerated flight for a hypothetical pivoted-wing airplane. $W/S = 20$ lb/sq ft.